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HUMAN BODY

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THE HUMAN BODY

A TEXT-BOOK OF ANATOMY, PHYSIOLOGY AND HYGIENE

BY

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FIFTH EDITION, REVISED

WITH PRACTICAL EXERCISES

BY

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PREFACE TO THE FIFTH EDITION.

The revision of this book was undertaken with the idea of bringing it into accord with the later developments of physiology, of simplifying the treatment of some parts, of expanding that of others, and of enriching the text with additional illustrations. Every effort has been made to avoid injuring those features of Professor Martin's work which have made the book so favorably known.

The changes in the first nine chapters are largely verbal; in the tenth and in some succeeding chapters, however, considerable alterations and additions have been made; Chapter XX. has been entirely rewritten, and Chapters XXIII. and an Appendix on Emergencies have been added. The Chapter on Narcotics, transferred to the appendix, is retained against the best judgment of the reviser, who believes that the questions involved are ethical and not physiological; it stands as Professor Martin wrote it, except that the paragraphs on certain drugs have been omitted.

The directions for demonstrations and experiments have been greatly enlarged and collected into an Appendix. They include the new requirements in Anatomy, Physiology and Hygiene, for admission to Harvard College and the Lawrence Scientific School. It is hoped that teachers will recognize the importance of practical work in physiology as in other sciences.

In accordance with Professor Martin's own judgment, the questions at the foot of the page have been omitted.

I have been indebted for practical suggestions to Dr. Margaret B. Wilson, of the Normal College, New York City.

G. W. F

CAMBRIDGE, MASS.,
August, 1898.

PREFACE TO THE FIRST EDITION.

THIS elementary textbook of Physiology has been prepared in response to many requests for a textbook framed on the same plan as the "Human Body," but abridged for the use of students younger, or having less time to give to the subject, than those for whom that book was designed. This demand, and the fact that a second edition of the "Human Body" was called for within twelve months of its publication, have shown me that I was not wrong in believing that the teachers of Elementary Physiology in the United States were ready and anxious for a textbook in which the subject was treated from a scientific standpoint, and not presented merely as a set of facts, useful to know, which pupils were to learn by heart like the multiplication table.

That some instruction in at least one branch of Natural Science should form a part of the regular educational curriculum is now so generally admitted that there is no need to insist upon it. But if this instruction simply means teaching by rote certain facts, no matter how important these facts may be, the proper function of Natural Science in a system of education is missed. Mere training of the memory (no unimportant matter) is otherwise sufficiently provided for in the usual school and college course of study: the true use of Natural Science in general education is differ-

ent. It should prepare the student in another way for the work of subsequent daily life, by training the observing and reasoning faculties.

As a department of science, modern Physiology is controlled mainly by two leading generalizations—the doctrine of the "Conservation of Energy" and that of the "Physiological division of labor." I have endeavored in this, as in the larger book, to keep prominent these leading principles; and, so far as is possible in an elementary book, to exhibit the ascertained facts of Physiology as illustrations of or deductions from them.

The anatomical and physiological facts which can be described in books of the size of the present must be pretty much the same in all. Apart from the attempt above mentioned to make elementary Physiology a more useful educational instrument than it has frequently hitherto been, the present volume differs from most others of its grade in having, as footnotes or as appendices to the chapters, simple practical directions, assisting a teacher to demonstrate to his class certain fundamental things. The demonstrations and experiments described necessitate the infliction of pain on no animal, and require the death of no creature higher than a frog, except such superfluous kittens, puppies, and rats as would be killed in any case, and usually by methods much less merciful than those prescribed in the following pages. The practical directions are, for the most part, reprints from a series of such which I drew up some years ago for a class composed of Baltimore teachers; those experiments which require costly apparatus have, of course, been omitted. The interest which my "Teachers' Class" took in its work, and the good use its members subsequently made of it, have encouraged me to believe that others might be glad of a few

hints as to things suitable to show to young students of Physiology.

It may be well to anticipate a possible objection. A few persons, some of them worthy of respect, assert that no experiments on an animal can be shown to a class without hardening the hearts of operator and spectators; even when, in accordance with the directions given in the following pages, the animal is anæsthetized and while in that condition is killed or its brain destroyed. This, from an experience of more than fifteen years in the teaching of practical physiology, I know to be not so. So far as the experiments described in the present book are concerned, their effect is most certainly humanizing. Young people are apt to be, not callous, but thoughtless as to the infliction of pain. When they see their teacher take trouble to kill even a frog painlessly, they have brought to their attention in a way sure to impress them, the fact that the susceptibility of the lower animals to pain is a reality, and its infliction something to be avoided whenever possible.

As the question of size is no unimportant one in relation to textbooks designed for junior students with many other subjects to learn, I may be permitted to say that though this volume contains more pages than most of those with which it will have to compete, I believe it is not really larger. The extra pages are due, in part to the above-mentioned appendices to the chapters, and in part to the great number and large size of the figures. My publishers had on hand electrotypes of the figures of the octavo edition, and have been able to utilize them in illustrating this briefer one much better than most textbooks of its scope, without proportionately increasing its price.

If I had relied solely on my own judgment the questions

at the foot of each page would have been omitted. But it was strongly represented to me by those whose opinion I had reason to value, that such questions were useful in enabling a student to test whether he had mastered his lesson, and that teachers who disliked such prearranged questions could and would ignore them. I hope that the pupils will use the questions and that their teachers will not.

Before concluding, I must express my sincere thanks to Miss Frances T. Bauman, who has given me the benefit of her many years' experience as an eminently successful teacher. She kindly read a large portion of the manuscript, and gave me much advice of which I have been glad to avail myself. I have also to acknowledge my indebtedness to Mr. W. H. Howell, Fellow of the Johns Hopkins University, who has corrected most of the proof-sheets and prepared the index.

H. N. M.

JOHNS HOPKINS UNIVERSITY,
August 10, 1883.

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THE HUMAN BODY.

CHAPTER I.

THE GENERAL STRUCTURE AND ARRANGEMENT OF THE HUMAN BODY.

Human Physiology is that department of science which has for its object the discovery and accurate description of the properties and actions of the living healthy human body, and the uses, or the *functions*, of its various parts. Physiologists endeavor to find out the work of the body as a whole, and of each of its parts, and the conditions under which this work is best performed. Upon this study is based the science of *Hygiene*, which is concerned with the laws and conditions of health.

Anatomy.—Clearly, to discover the use and mode of working of each part of the body we must learn about the parts; this study is *Human Anatomy*. When the body is examined from without, it is seen to be a complicated structure with its head and neck, trunk and limbs, and the many smaller but distinct parts which enter into the formation of the larger ones, as eyes, nose, ears, and mouth to form the face. Dissected, its complexity is seen to be far greater; we then learn that it is made up of many hundreds of diverse parts, each having its own form, structure, and purpose, but all working harmoniously together in health.

Summary.—*Anatomy* deals with the form, structure, and connections of the parts of the body; *Physiology* with the uses, or functions, of the parts, and the manner of their working; *Hygiene* with the conditions of life which promote the health of the body.

Microscopic Anatomy or Histology.—Examination of the body's surface shows that a number of different materials enter into its formation, such as hair, nails, skin, and teeth. By feeling through the skin, we find harder and softer solid masses beneath; by piercing it, we find liquid blood.

A closer examination of any of its parts, as the hand, discloses the same variety of materials. We see the *skin* and *nails*; when the skin is dissected off we find yellowish-white *fat*; beneath the fat lies a number of soft red masses, the *muscles* (which correspond to the *lean* of meat); under the muscles, again, are hard, whitish *bones*; the ends of bones which form the joints are covered by still another substance, *gristle* or *cartilage*. Finally, binding skin, fat, muscles, and bone together, we discover a tough stringy material, different from all, which is called *connective tissue*. If we take any other portion of the body, as the foot, we arrive at a similar result; it, too, is made up of a number of different materials, or tissues, which, though in this case identical with those found in the hand, are arranged in a different way so as to perform another function (just as wood and nails may be used to build a house or a bridge, but are put together in a different manner in the two cases); or we find, as in the eye, some identical and some quite different materials.

That branch of anatomy which deals with the arrangement of the materials used in the construction of the parts of the body is called *histology*, or, since it is mainly carried on with the aid of the microscope, *microscopic anatomy*.

Tissues.—Each of the primary building materials which can be recognized, either with or without the microscope, as entering into the construction of the body, is called a *tissue*; we speak, for example, of muscular tissue, fatty tissue, bony tissue, cartilaginous tissue, and so forth; each tissue has certain properties in which it differs from all the rest, and which it preserves in whatever part of the body it may be found. It is also, when examined with a microscope, characterized by certain appearances which are always the same for the same tissue no matter where it is found. The total number of important tissues is not great; the variety in structure and use which we find in the parts of the body depends mainly on the diverse ways in which the tissues are combined.

Organs.—Each distinct portion of the body with a special use or function is called an *organ*; thus, the hand is an organ of prehension; the eye, the organ of sight; the stomach, an organ of digestion; and so forth.

Summary.—The human body is made up of a limited number of *tissues*;* each tissue has a characteristic appearance, by which it can be recognized with the microscope, and one or more distinctive properties which fit it for some special use; thus, it may be tough, and suited for binding other parts together; or rigid, and adapted to preserve the shape of the body; or have the power of contracting and thus of moving parts to which its ends are attached.

* The various tissues of the body will be considered in more detail in connection with the study of the special organs. The more important are: 1. Bony tissue. 2. Cartilaginous tissue. 3. White fibrous connective tissue. 4. Yellow elastic tissue. 5. Glandular tissue, of which there are many varieties. 6. Respiratory tissues. 7. Fatty tissue. 8. Sense organ or irritable tissues. 9. Nerve cell tissue. 10. Nerve fibre tissue. 11. Striped muscular tissue. 12. Unstriped muscular tissue. 13. Epidermic and epithelial tissue.

The tissues are variously combined to form the *organs* of the body, of which there are very many, differing in size, shape, and structure; some organs contain only a few tissues; others, a great many; some possess only tissues which are found also in other organs, others contain one or more tissues peculiar to themselves; but wherever an organ is found, it is constructed and placed with reference to the performance of some duty; the organs are the machines which are found in the factory represented by the body, and the tissues are the materials used in building the machines; or, using another illustration, we may, with Longfellow, compare the body to a dwelling-house; and then go on to liken the tissues to the brick, stone, mortar, wood, iron, and glass used in building it; and the organs to the walls, floors, ceilings, doors, and windows, which, made by combining the primary building materials in different ways, have each a purpose of their own, and all together make the house.

The General Plan on which the Body is Constructed.— When we desire to gain a general idea of the structural plan of any object we examine, if possible, sections made through it in different directions: the botanist cuts the stem of the plant he is examining lengthwise and crosswise, and studies the surfaces thus laid bare; the geologist, investigating the structure of any portion of the earth's crust, endeavors to find exposed surfaces in cañons, in railway cuttings, and so forth, where he may see the strata exposed in their natural relative positions; so, also, the best method of getting a good general idea of the way in which the parts of the human body are put together is to study them as laid bare by cuts made in different directions.

If the whole body is divided into right and left halves, the cut surface of the right half resembles Fig. 1. Such a

section shows us, first, that the body essentially consists of two main tubes or cavities, separated by a solid bony partition. The larger cavity, *b*, *c*, known as the *ventral cavity*, lies on the front side, and contains the organs of circulation, respiration, and digestion. It does not reach into the neck, but is entirely confined to the trunk. The smaller cavity, *a*, *a'*, is tubular in the trunk region, but passes on through the neck, and widens out in the skull; it is known as the *dorsal* or *neural cavity*, and contains the most important nervous organs, i.e. the brain, *N'*, and spinal cord, *N*. In the partition between the two cavities is a stout bony column, the back-bone or spine, *e*, *e*, which is made up of a number of short thick bones arranged one on the top of another.

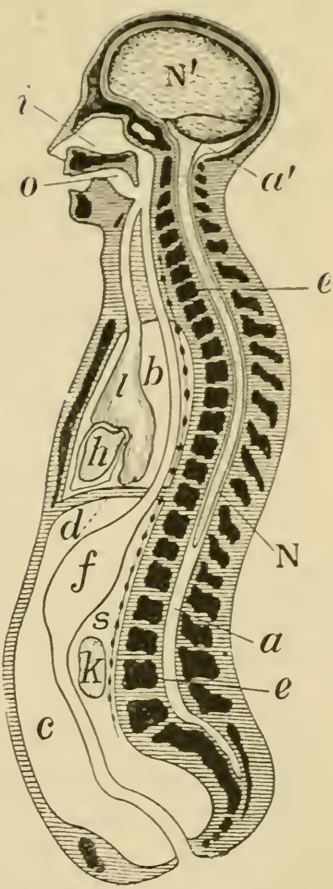


FIG. 1.—Diagrammatic longitudinal section of the body. *a*, the neural tube, with its upper enlargement in the skull cavity at *a'*; *N*, the spinal cord; *N'*, the brain; *ee*, vertebræ forming the solid partition between the dorsal and ventral cavities; *b*, the pleural, and *c*, the abdominal division of the ventral cavity, separated from one another by the diaphragm, *d*; *i*, the nasal, and *o*, the mouth chamber, opening behind into the pharynx, from which one tube leads to the lungs, *l*, and another to the stomach, *f*; *h*, the heart; *k*, a kidney; *s*, the sympathetic nervous chain. From the stomach, *f*, the intestinal tube leads through the abdominal cavity to the posterior opening of the alimentary canal.

Man is a Vertebrate Animal.—The presence of these two chambers with the solid partition between them is a primary fact in the anatomy of the body; it shows that man is a *vertebrate animal*, that is, a back-boned animal, and belongs to the same great group as

fishes, reptiles, birds, and beasts.* Sea anemones, clams, and insects are invertebrate animals, and sections made through any of them from the head to the opposite end would show nothing like the two main cavities with a back bone between them characteristic of the vertebrates.

Contents of the Two Chief Cavities of the Body.—Examination of Fig. 1 shows that the ventral cavity is entirely closed, though some of the organs which lie in it are hollow and communicate with the exterior. On the head we find the nose, *i*, and the mouth, *o*, opening on the *ventral side*, that is, on that surface of the body next which the ventral cavity lies. The nose chamber joins the mouth chamber at the throat, from which two tubes run down through the neck and enter the ventral cavity. One of these tubes, placed on the ventral side of the other, is the *windpipe*, and leads to the lungs, *l*; the other is the *gullet*, and leads to the stomach, *f*. From the stomach another tube, *the intestine*, returns to the outside at the lower or posterior † end of the trunk. Mouth, throat, gullet, stomach, and intestine together form *the alimentary canal*, which begins in the head above or anterior to the ventral cavity, enters this cavity at the bottom of the neck and runs on through it, to pass out again posteriorly; just as a tube might pass through a box, in at one end and out at the other, without opening into it at all. In

* The main groups in which animals are arranged are: 1. *Vertebrata*, or back-boned animals. 2. *Mollusca*, including snails, slugs, clams, oysters, etc. 3. *Arthropoda*, including flies, moths, beetles, centipedes, lobsters, spiders, etc. 4. *Vermes*, including worms of various kinds. 5. *Echinodermata* (hedgehog-skinned animals), including sea-urchins, star-fishes, etc. 6. *Cœlenterata*, the sea anemones and their allies. 7. *The Protozoa*, all microscopic and very simple in structure.

† In anatomy the head end of an animal is spoken of as *anterior*, and the opposite end as *posterior*, no matter what may be the natural standing position of the creature.

addition to the lungs and the greater part of the alimentary canal, the ventral cavity contains several other organs, among the more important of which are (Fig. 1) the *heart*, *h*; the *kidneys*, *k*; the *sympathetic nerve centers*, *s*; and the large digestive organs.

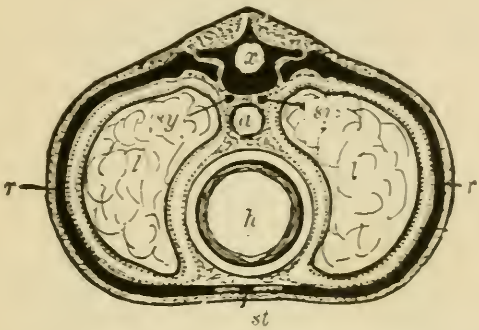


FIG. 2.—A diagrammatic section across the body in the chest region. *x*, the dorsal tube, which contains the spinal cord; the black mass surrounding it is a vertebra; *a*, the gullet, a part of the alimentary canal; *h*, the heart; *sy*, sympathetic nervous system; *ll*, lungs; the dotted lines around them are the pleuræ; *rr*, ribs; *st*, the breastbone.

If we examine a section made across the trunk of the body, say about the level of the middle of the chest (Fig. 2),

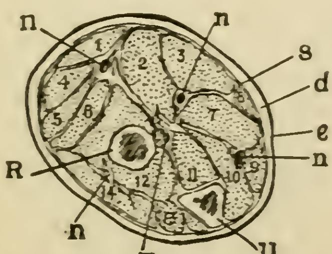


FIG. 3.—A section across the forearm a short distance below the elbow-joint. *R* and *U*, its two supporting bones, the radius and ulna; *e*, the epidermis, and *d*, the dermis, of the skin; the latter is continuous below with bands of connective tissue, *s*, which penetrate between and invest the muscles (1, 2, 3, 4, etc.); *n*, *n*, nerves and vessels.

we find on the dorsal side the neural tube, *x*, and in it the spinal cord, which is not represented in the figure. The part surrounding the neural tube and represented by the

black, star-shaped mass is part of the spinal column. The chest cavity is enclosed by the spinal column, the ribs *r, r*, and the breastbone *st*, and contains the lungs, *l, l*; the heart, *h*; the gullet, *a*; and the sympathetic centres, *sy, sy*.

The Limbs.—If our section is made across one of the limbs, we find no such arrangement of cavities. Each limb has a supporting axis made of one or more bones (as seen at *U* and *R*, Fig. 3, which represents a section made across the forearm near the elbow joint), but soft parts, chiefly muscles, are closely packed around this axis, and the whole is enveloped by skin.

Man's Place among Vertebrates.—Although man's structural plan in its broad features simply indicates that he is a vertebrate animal, yet he is much more like some vertebrates than others. The hair covering his body, and the organs producing milk for the nourishment of the infant by its mother, are entirely absent in fishes, reptiles, and birds, but are possessed by ordinary four-footed creatures and by whales, bats, and monkeys. The organs which form milk are the *mammary glands*, and all kinds of animals whose females possess them are known as *Mammalia* *: man is, therefore, a Mammal. One of the most important characteristics of the Mammalia is a cross-partition, called the *midriff* or *diaphragm*, (*d*, Fig. 1) which separates the ventral cavity into an anterior and a posterior part; the upper or anterior story is the *chest* or *thoracic cavity*; the lower or posterior, the *abdominal cavity*. The chest contains the heart, lungs, and most of the gullet;

* Zoologists classify vertebrate animals in five groups. 1. *Pisces*, including all true fishes, as sharks, eels, salmon, shad, perch, etc., but excluding the so-called shellfish, as oysters, clams, and lobsters, which are not vertebrates at all. 2. *Amphibia*, frogs, toads, newts, salamanders, etc. 3. *Reptilia*, lizards, alligators, turtles, snakes. 4. *Aves*, birds. 5. *Mammalia*.

the abdomen contains the lower end of the gullet (which pierces the diaphragm), the stomach, the intestine, the kidneys, and most of the organs making digestive liquids. The

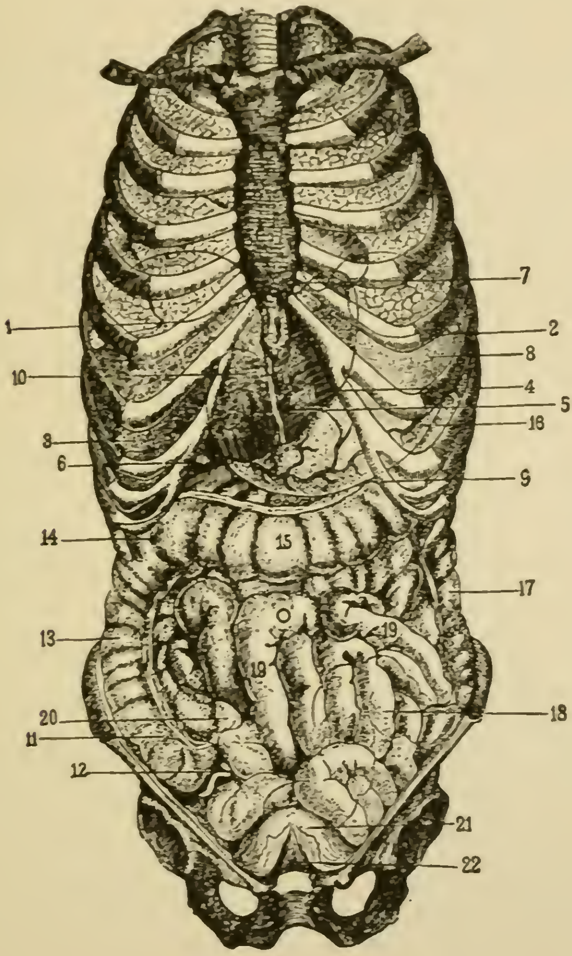


FIG. 4.—Diagram showing the position of the thoracic and abdominal organs. 1, lower border of right lung; 2, the same of the left lung; 3, liver, right lobe; 4, liver, left lobe; 5, suspensory ligament of the liver; 6, fundus of gall-bladder; 7, cardia of stomach; 8, fundus of stomach; 9, lower border of stomach; 10, position of pylorus; 11, cæcum; 12, vermiform appendix; 13, ascending colon; 14, right flexure of colon; 15, transverse colon; 16, position of left flexure of colon; 17, descending colon; 18, portion of sigmoid colon, concealed by, 19, convolutions of the small intestine; 20, termination of ileum, ascending from right to left; 21, bladder, distended, partly covered by peritoneum; 22, the part of the bladder which is not covered by peritoneum.

sympathetic nerve centres run through both abdomen and chest, and extend beyond the latter into the neck.

The ventral cavity, opened from the front, but with its contents undisturbed, is shown in Fig. 4. We there see, in the chest, the lungs and the heart, the latter largely covered by the lungs. Below the diaphragm is the abdominal cavity, containing the liver, the stomach, the intestines, and the bladder.

Summary.—Man is a vertebrate animal, because his body presents dorsal and ventral cavities separated from one another by a hard partition. The dorsal cavity contains the brain and spinal cord, and reaches into the head. The ventral cavity stops at the bottom of the neck and contains the main organs of circulation, respiration, and digestion.

Man belongs to that subdivision of vertebrates known as Mammalia (1) because his body is covered by hair; (2) because of the presence of mammary glands; (3) because the ventral cavity is completely separated by the diaphragm into thorax and abdomen.

That man is intellectually superior to any other animal, and stands supreme in the world, can be doubted by no one, especially when we consider his power of forming concepts of right and wrong, and his feeling of moral responsibility. But anatomists have only to deal with man's body as a material object, and as such they classify it among other animal bodies according to the degree of resemblance found between them.

CHAPTER II.

THE MICROSCOPICAL AND CHEMICAL COMPOSITION OF THE BODY.

What are the Tissues?—Having gained some idea of the general arrangement of the larger parts of the body, we may next consider the minute structure of the tissues. The tissues are made up of *cells* * which are so small that a single one can be seen only with the help of a microscope. In a fully formed cell (Fig. 5) we find three parts: (1) a *cell body* made up of a soft granular substance, protoplasm; (2) a smaller and less granular *cell nucleus* embedded in the cell body; and (3) a tiny dot, the *nucleolus*, lying in the nucleus. Cells vary much in form and size, though all are very small. A great many float in our blood, and are more or less rounded (*b*). Others are flattened to form thin scales as in Fig. 6, which represents cells scraped from the peritoneum, the membrane lining the wall of the abdomen. Still others are elongated, as *c*, Fig. 5. If greatly elongated, the cell becomes a slender thread, called a *fibre*; long fibres are often made up of these elongated cells, joined end to end. Examples of fibres are shown in Figs. 35 and 85. Speaking in general, we may

FIG. 5.—Forms of cells from the body.

* So called from an old belief that they were little bags or chambers. Most cells are really solid or semi-solid throughout.

say that the whole body consists of tiny cells, either rounded and thick, flat and thin, or elongated to form fibres. Just as a wall is built of distinct bricks or stones, so an organ is made up of a number of cells.

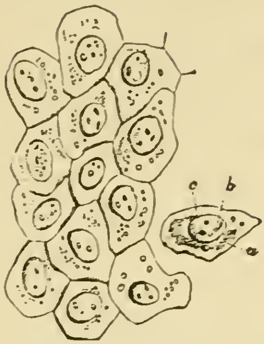


FIG. 6.—Flat cells from the surface of the lining membrane of the abdomen (peritoneum): *a*, cell-body; *b*, nucleus; *c*, nucleoli.

All the solid parts of the body are either cells or fibres which have grown from cells, except something which corresponds pretty closely to the mortar which lies between the bricks of a wall and holds them together. This latter material, known in the body as *intercellular substance*, is in some places abundant, in others scanty or absent. Wherever found, the intercellular substance is made by the cells which lie embedded in it; they pass it out from their surfaces and repair it when necessary.

Summary.—Cells thus essentially make up the body and do its work; their form and arrangement determine the form of the organs; their activity, the function of the organs. For example, the bone cells have the power of forming the intercellular substance which gives the hardness to the bony skeleton; the muscle cells are long fibres and by their contraction move the bones to which they are attached; the cells embedded in the wall of the stomach secrete the peculiar solvent fluid used in digestion.

Anatomy may be defined as the study of the forms which cells and intercellular substances assume; physiology, as the study of the specific activity of the cells.

The Physiological Division of Labor.—In a tribe of wandering savages, living by the chase, we find that each man has no special occupation of his own; he collects his own food, provides his own shelter, defends himself from

wild beasts and his fellow men. In a civilized nation, on the contrary, we find that most men have some one particular business: farmers raise crops and cattle; cooks prepare food; tailors make clothes; and policemen and soldiers protect the property and lives of the rest of the community; in other words, we find a *division of labor*. The more minute the division of labor in a nation, the more advanced is it in civilization; so also an animal is higher or lower in proportion as the duties necessary for maintaining its existence are distributed among different tissues and organs. The amœba, one of the lowest animals, feels, moves, catches and digests food, and breathes, although it consists of but one cell. Higher animals perform these functions by means of different cells set apart in special organs. This specialization of function is called *differentiation*.

Results of a Division of Labor.—From the division of employments in advanced communities, several important consequences result. In the first place, when every one devotes his time mainly to one kind of work, all kinds of work are better done: the man who always makes boots becomes more expert than the man who is engaged on other things also; he can not only make more boots in a given time, but he can make better boots. In the second place, when various employments are distributed among different persons, there arises a necessity for a new kind of industry in order to convey the special product of any individual not needed by himself to others who may want it, and to bring him in return such excess production of others as he may need. The conveyance of food from the country to cities, and of manufactures to agricultural districts, are examples of this sort of labor in civilized communities. Finally, there is developed a necessity for arrangements by which, at any

given time, the activity of individuals shall be regulated in accordance with the wants of the whole community or of the world at large.

Exactly similar phenomena result from the division of physiological labor in the human body. Each tissue and organ does a special work for the whole body and in turn relies on the others for their aid; thus every sort of necessary work is better performed; the tissue or organ, since it has nothing else to look after, is constructed with reference only to its own particular duty, and is capable of doing it extremely well. This, however, necessitates a distributing mechanism by which all excess products of the various organs shall be carried to others which require them; and a regulating mechanism by which the activities of each shall be controlled in accordance with the needs of the whole body. We accordingly find a set of organs, the *heart and blood vessels*, which circulate the blood so that in its course through the body it gets something from and gives something to each organ through which it flows: and a set of *nervous organs* which ramify in every direction and regulate the activity of its parts.

The Chemical Composition of the Body.—If we go beyond the tissues to seek the ultimate constituents of the body, we must lay aside the microscope, and call upon chemistry to discover what elements and compounds make up the cells and intercellular substance.

Elements found in the Body.—Of the many elements discovered by chemists, only seventeen have been found in the healthy human body.* Very few exist in it uncombined,

* The elements found in the body in health are carbon. hydrogen. nitrogen. oxygen. sulphur. phosphorus. chlorine. fluorine, silicon. sodium, potassium. lithium, calcium, magnesium, iron, manganese, and iodine.

although some oxygen is dissolved in the blood and is also found, mixed with nitrogen, in the lungs.

Chemical Compounds existing in the Body.—These are so numerous that it would be a long task to enumerate them, but some require mention. They may be divided into organic and inorganic. The general distinguishing characteristic of the organic constituents of the body is that if dried they would burn in a fire; of the inorganic components, that they could not be made to burn.

Inorganic Constituents of the Body.—Of the inorganic constituents of the body, *water* and *common salt* are the most important; they are found in all the organs and liquids of the body. Phosphate and carbonate of lime are also found in large proportions in the bones and teeth, and free hydrochloric acid (muriatic acid) is always found in healthy gastric juice, which dissolves some kinds of food in the stomach.

Organic Constituents of the Body.—All organic constituents of the body contain carbon, hydrogen, and oxygen; some contain nitrogen also. There are three chief kinds of them, viz., albumens, fats, and carbohydrates.

Albuminous or Proteid Substances.—These are by far the most characteristic organic compounds existing in the body; they are known only as obtained from living beings, as they have never yet been artificially constructed in the laboratory; a good example is found in the white of an egg, which consists chiefly of albumen dissolved in water. All the tissues of the body which have any marked physiological property contain some albuminous substance, only such things as hairs, nails, and teeth being devoid of them. All albuminous bodies contain nitrogen, carbon, hydrogen, and oxygen; most of them sulphur and phosphorus in addition. The more important ones found in the body are, (1) *Serum albumin*,

which is very like egg albumin, and is found dissolved in the blood; (2) *Fibrin,* which forms in blood when it clots; (3) *Myosin,* which is found in the muscles and which by "setting" or coagulating after death causes the death stiffening; (4) *Casein,* which is found in milk, and forms the main bulk of cheese.

Fats belong to the organic compounds in the body which contain no nitrogen; they consist solely of carbon, hydrogen, and oxygen. The chief fats in the body are *palmitin, stearin,* and *olein;* by proper chemical treatment each can be split up into *glycerine* and a fatty acid, i.e. *palmitic, stearic,* or *oleic* as the case may be.

The Carbohydrates also consist entirely of carbon, hydrogen, and oxygen; they belong to the same class of substances as starch and sugar. The most important carbohydrate found in the body is *glycogen,* a sort of starch found stored up in the liver and muscles. *Glucose* or *grape sugar* also exists in the body; and *lactose* or *milk sugar* is found in milk.

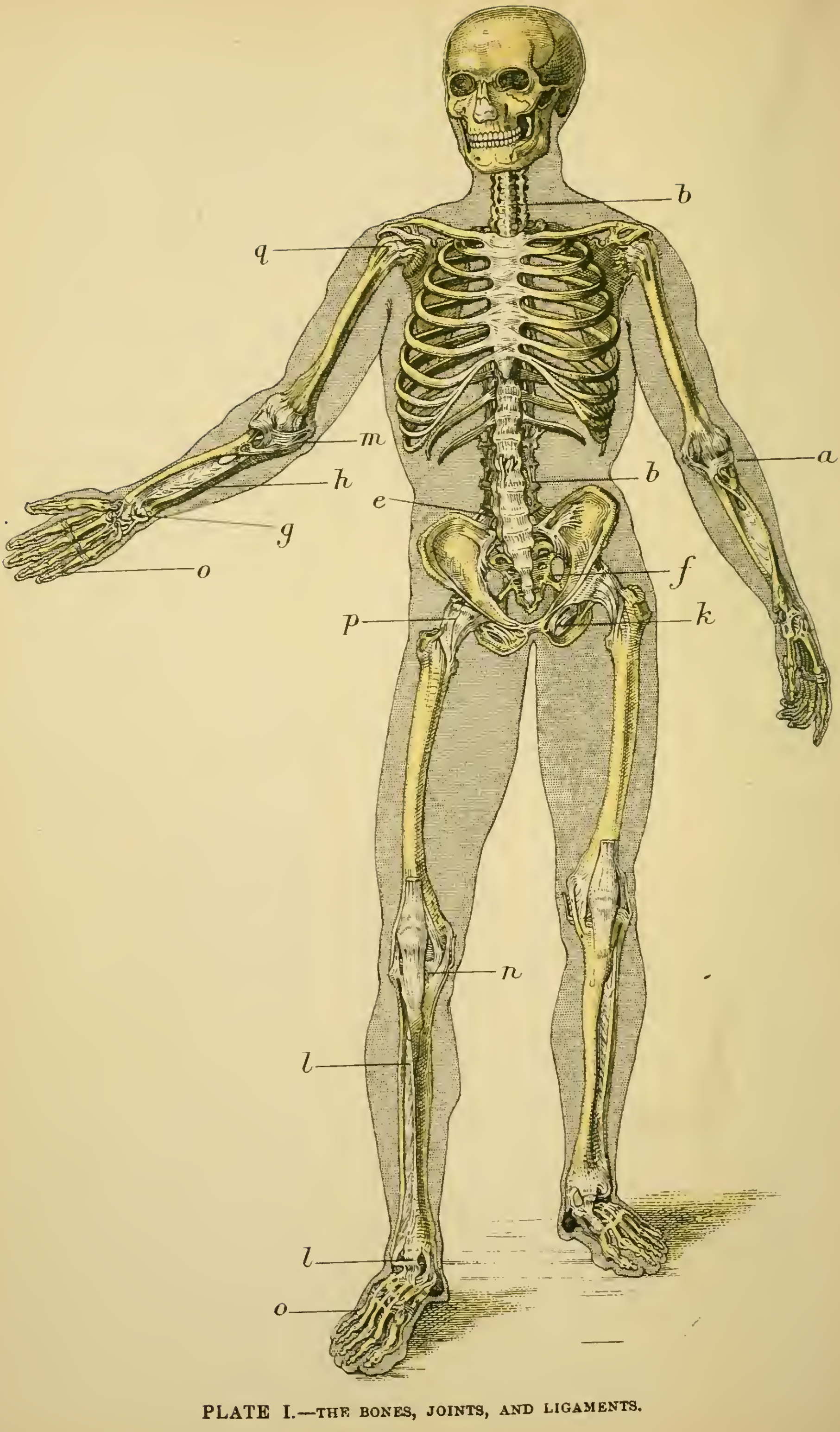


PLATE I.—THE BONES, JOINTS, AND LIGAMENTS.

EXPLANATION OF PLATE I.

A front view of an adult human skeleton to illustrate the mode in which the bones are connected together at the different joints.

For the names of the bones consult the description of Fig. 8, which commences on page 20.

a Ligaments of the Elbow Joint.

b The Ligament which is connected with the ventral surfaces of the bodies of the Vertebræ.

e Ligament connecting the Innominate Bone to the Spine.

f Ligament connecting the Innominate Bone to the Sacrum.

g The Ligaments of the Wrist Joint.

h The Membrane which fills up the interval between the two bones of the Fore Arm.

l A similar Membrane between the two bones of the Leg, and, lower down, *l*, ligaments of the Ankle Joint.

k A Membrane which fills up a hole in the Innominate Bone.

n Ligaments of the Knee Joint.

oo Ligaments of the Toes and Fingers.

p Capsular (bag-like) Ligament of the Hip Joint.

q Capsular Ligament of the Shoulder Joint.

CHAPTER III.

THE SKELETON.

The Skeleton * of the human body is composed of three materials: *bone*, *cartilage*, and *connective tissue.*

The Bones form the main supporting framework of the body, and determine its shape; they provide levers on which the muscles pull, and they surround cavities in which soft, delicate organs, as brain, spinal cord, and heart, may lie in safety.

Cartilage caps the ends of bones, forming elastic pads with smooth surfaces for the joints. It is also used instead of bone in some parts of the skeleton where considerable flexibility is required, as at the anterior ends of the ribs. Cartilage affords one of the best tissues of the body for the examination of intercellular substance. A thin slice of it highly magnified, Fig. 7, shows the *cartilage cells*, *a*, *b*, scattered through an almost structureless material. Very young cartilage consists of the cells only, but these lay down intercellular substance around them, until at last it forms the main bulk of

* There are two kinds of skeleton in the animal kingdom: the external skeleton or *exoskeleton*, and the internal skeleton or *endoskeleton*. The exoskeleton is made by the skin, either in it or on it; examples are found in the shells of clams and lobsters; the scales of fishes and snakes; the tortoise-shell of turtles; the feathers of birds; the hair and claws of beasts. In man the exoskeleton is only slightly developed; hair, nails, and teeth belong to it.

the cartilage, and gives the elasticity and flexibility for which cartilage is used in the body.

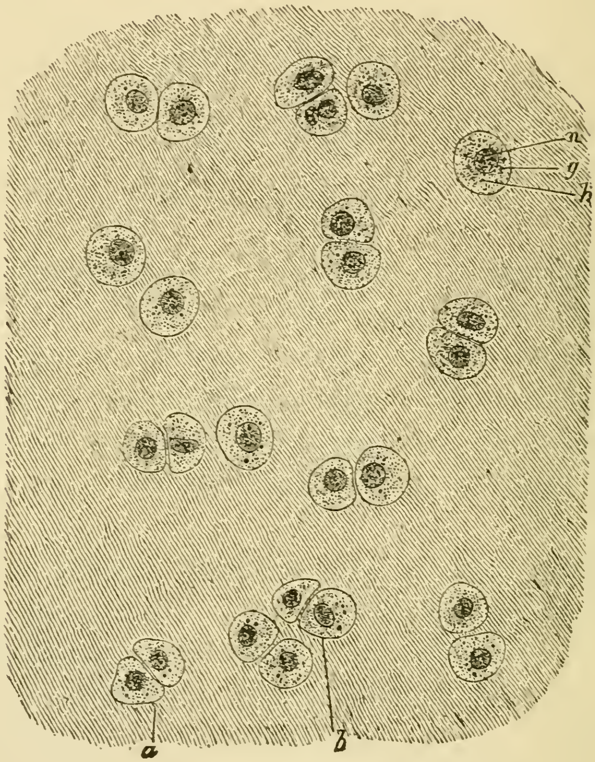


FIG 7.—A thin slice of cartilage highly magnified.

Connective Tissue occurs partly in the form of stout cords —*ligaments*—which bind different bones together, or which, as *tendons*, attach muscles to bones. It partly supplements the coarser bony skeleton by a fine network which extends through all the soft parts of the body and makes a sort of microscopic skeleton, or supporting meshwork, for its cells. It is laid down as a soft packing material, a good deal like raw cotton, in the crevices between different organs, as shown at *s*, Fig. 8, between the muscles of the forearm. This tissue is, in fact, so widely spread through the body, from the skin

outside to the lining of the alimentary canal within, that if we could employ a solvent which would remove everything except this connective tissue, a very perfect model of all the organs would be left; something like a skeleton leaf, but far more minute in its tracery.

Articulations and Joints.—If the pieces forming the hard framework of the body were put together like the beams and planks of a frame house, the whole mass would be rigid and immovable; we could not raise a hand to the mouth, or put one foot before another. In order to attain mobility the bony skeleton is made up of more than two hundred separate pieces, joined together; the points where they meet are called *articulations*. An articulation in which a considerable range of movement is per-

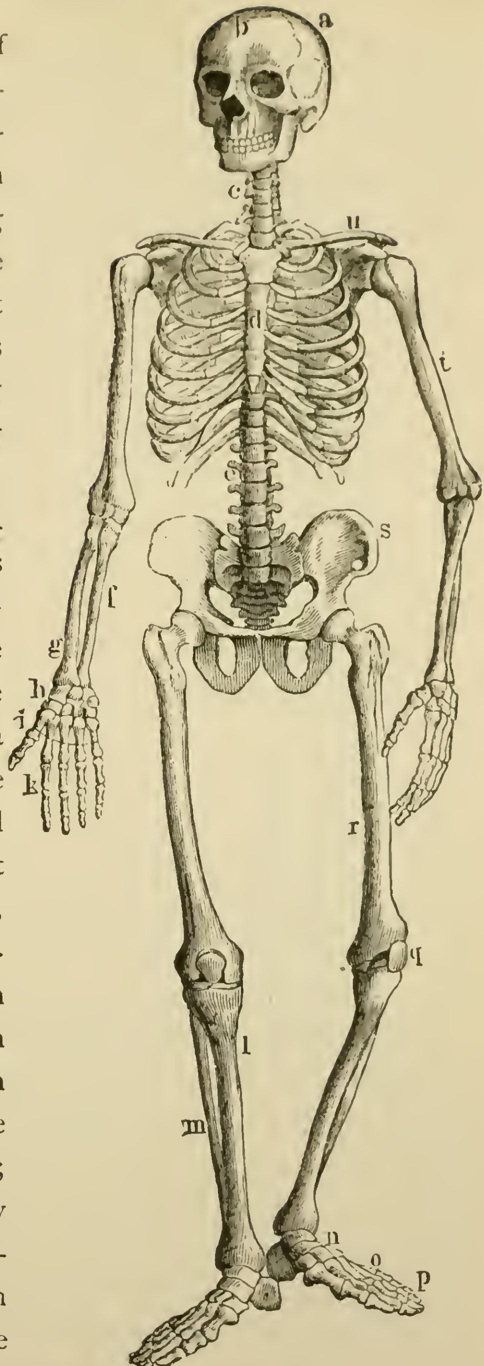


FIG. 8.—The bony and cartilaginous skeleton.

mitted is called a *joint*. The ends of bones which rub against one another in a joint are covered by a smooth layer of cartilage.

The Bony Skeleton (Fig. 8) consists of an *axial skeleton*, supporting head, neck, and trunk, and an *appendicular skeleton*, supporting the limbs and attaching them to the trunk.

The Axial Skeleton.—The fundamental portion of this is the *backbone, spinal column*, or *spine*, partly seen at *e* and *c*, Fig. 8, and represented isolated from the rest of the bones and viewed from the left side in Fig. 9. It forms an axis, on which the rest of the body is carried. On the upper end of the vertebral column is the *skull*, *a*, *b*, Fig. 8, and attached by ligaments to the under surface of the skull is the *hyoid bone*, to which the root of the tongue is fastened.

Slender bones, called ribs, are attached by their dorsal ends to the sides of part of the spine; they curve round the sides of the chest and are united in front to the *sternum*, or *breast-bone*, *d*, Fig. 8.

Skull, hyoid bone, vertebral column, ribs, and sternum together form the axial skeleton.

The appendicular skeleton consists of the *pectoral* and *pelvic girdles*, attaching the limb bones to the axial skeleton, and of the limb bones themselves.

The Pectoral Arch or Girdle consists on each side of a *collar bone* or *clavicle*, *u*, and a *shoulder blade* or *scapula*. The scapula, Fig. 8, is a flat, triangular bone, lying on the back of the chest outside the ribs. The clavicle is a slender curved bone like an italic *f* in form. Its outer end is attached to the scapula, and its inner end to the top of the sternum. It serves to support the shoulder joint, and to prevent it from falling backwards or inwards toward the front of the chest. It is absent in creatures which use their fore limbs for walking

only, as horses, dogs, and cattle, but is well developed in monkeys and bats.

The skeleton of the upper limb consists of: (1) The arm bone or *humerus*, *t*, Fig. 8, which extends from the shoulder to the elbow, and meets the scapula at the shoulder joint; (2) of two forearm bones, the *radius*, *g*, and *ulna*, *f*, the radius being on the thumb side; and (3) of twenty-seven hand bones. Of the hand bones eight, the *carpal bones*, *h*, lie in the wrist; five, the *metacarpal bones*, *i*, in the palm of the hand; and fourteen, the *phalanges*, *k*, in the thumb and fingers—two for the thumb, and three for each finger.

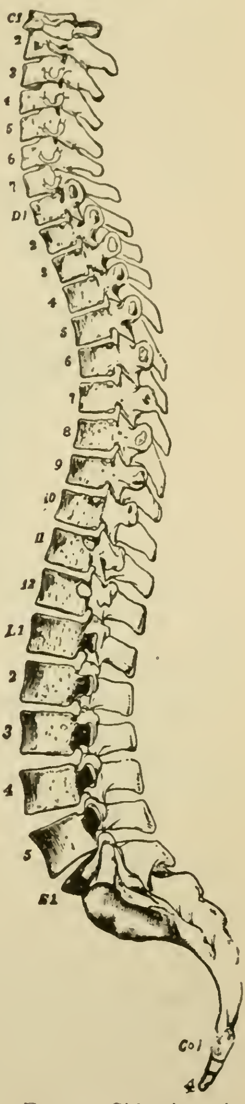


FIG. 9.—Side view of the spinal column.

The Pelvic Arch or Girdle consists of a single bone, the *os innominatum*, *s*, on each side; this is firmly fixed at its dorsal end to the lower part of the backbone, meets its fellow ventrally at the lower end of the abdomen, and bears a deep socket on its outer side, into which the upper end of the thigh bone fits.

The Skeleton of the Lower Limb consists of: (1) The *thigh bone* or *femur*, *r*, the longest bone in the body, which bears on its upper end a hemispherical knob fitting into a hollow on the outside of the os innominatum, to form the hip joint; (2) of two bones, *tibia* and *fibula*, *l* and *m*, in the lower leg, the former on the inside; (3) of the knee cap or *patella*, *q*, in front of the knee joint; (4) of twenty-six foot

bones. Of the foot bones seven, the *tarsal bones*, *n*, lie below the ankle joint; five, the *metatarsal bones*, *o*, are anterior to

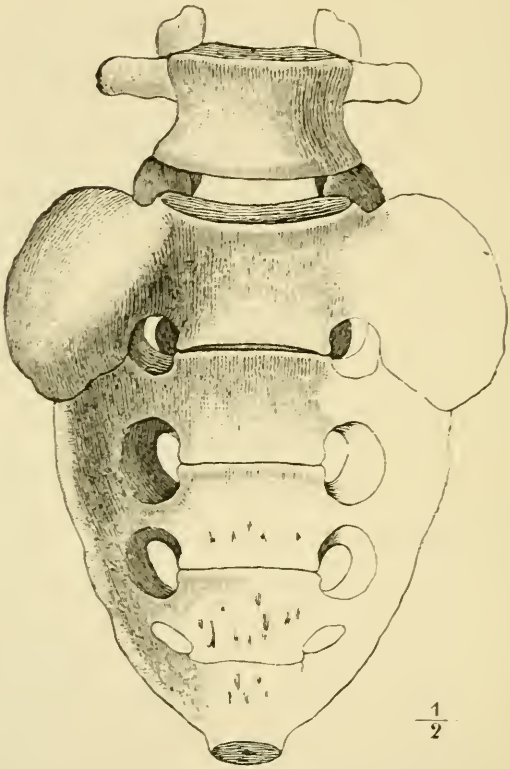


FIG. 10.—The last lumbar vertebra and the sacrum seen from the ventral side.

these in the front half of the sole of the foot; and fourteen *phalanges*, *p*, are found in the toes, two in the great toe and three in each of the others.

The Vertebral Column (Fig. 9).—The upper portion of the spine consists of twenty-four separate bones, each called a *vertebra;* these are placed one above the other, and separated by elastic pads of cartilage and connective tissue. Seven vertebræ (*cervical*, *C* 1–7) are found in the neck; twelve (*dorsal*, *D* 1–12) lie at the back of the chest and carry the

ribs; and five (*lumbar*, *L* 1–5) are in the loins or "small of the back."

Below the separate vertebræ we find the *sacrum* (*S* 1), which is seen in Fig. 10, with the lowest lumbar vertebra. In childhood the sacrum consists of five distinct vertebræ, but these grow together afterwards, though cross ridges remain indicating the original lines of separation. Below the sacrum, forming the tip of the spine, is the coccyx (*Co* 1–4, Fig. 9), a single bone in adults, but four bones in children.

The Structure of a Vertebra.—Those vertebræ which remain separate resemble one another in general form. As an example we may take the eleventh from the skull, i.e. the fourth dorsal vertebra (Figs. 11 and 12).

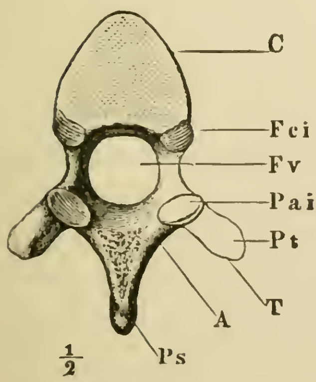


FIG. 11.

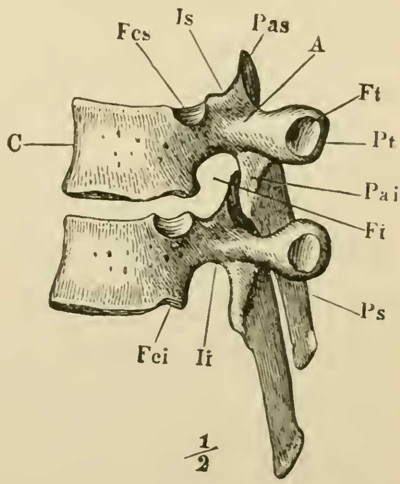


FIG. 12.

FIG. 11.—A dorsal vertebra seen from behind, *i.e.* the end turned from the head.

FIG. 12.—Two dorsal vertebræ viewed from the left side, and in their natural relative positions. *C*, the body; *A*, neural arch; *Fv*, the neural ring; *Ps*, spinous process; *Pas*, anterior articular process; *Pai*, posterior articular process; *Pt*, transverse process; *Ft*, facet for articulation with the tubercle of a rib; *Fcs*, *Fci*, articular surfaces on the centrum for articulation with a rib.

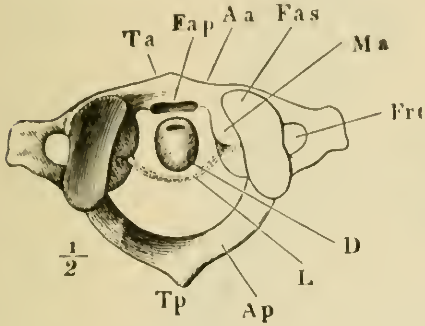
In it we find (1) a thick bony mass, *C*, rounded on the sides and flattened above and below where it faces its neighbors, called the *centrum* or *body* of the vertebra. The series

of vertebral bodies forms the bony partition (*e*, *e*, Fig. 1) already mentioned as existing in the trunk between the neural and ventral cavities. (2) The arch, *A*, which is attached to the dorsal side of the centrum, is called the *neural arch*, and with the centrum it forms the neural ring (*Fv*). By the arrangement of the vertebræ one above the other, the successive neural rings form the neural tube, in the cavity of which the spinal cord lies. (3) Bony processes project from the body and the arch (Figs. 11 and 12): these are (*a*) the *spinous process* (*Ps*) which points dorsally and with its fellows forms the ridge of the spine; (*b*) the *transverse processes* (*Pt*), one on either side, which in the dorsal region support the ribs; and (*c*) the *articular processes* (*Pas*, *Pai*), four on each vertebra, which form the points of contact with the adjoining vertebræ above and below.

Where the arch joins the centrum it is narrowed to a stalk or *pedicle*, *Ii*, Fig. 12. When the vertebræ are placed together in their natural relative positions, apertures (*Fi*), which lead into the neural canal, are left between their narrower portions; through these apertures (called the *intervertebral foramina*) nerves pass into or out from the spinal cord.

The Atlas and Axis.—The first and second cervical vertebræ, however, differ considerably from the others. The first, called the *atlas* (Fig. 13), carries the head; it has a very small body and a very large neural ring. A ligament, *L*, divides the ring into a ventral and a dorsal portion; the spinal cord passes through the latter and a bony peg, *D*, lies in the former. The peg is the *odontoid* or *tooth-like process* which rises from the second cervical or *axis vertebra* (Fig. 14) and forms a pivot around which the atlas, carrying the skull with it, rotates when the head is turned from side to side. On the anterior (upper) surface of the atlas are a pair of shal-

low hollows, *Fas*. A pair of knobs on the under surface of the skull (Fig. 20) glide in these hollows during nodding movements of the head.



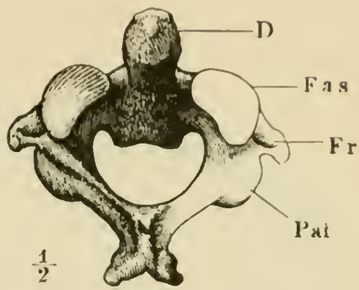


FIG. 13. FIG. 14.

FIG. 13.—The *atlas*. FIG. 14.—The *axis*. *Aa*, body of atlas. *D*, odontoid process of axis; *Fas*, facet on upper side of atlas with which the skull articulates; and in Fig. 13, anterior articular surface of axis; *L*, transverse ligament; *Frt*, vertebral foramen.

Value of the Structural Arrangement of the Spinal Column.—When the backbone is viewed from one side (Fig. 9) it is seen to present four curvatures: one in the neck, convex ventrally, is followed by a curve in the opposite direction in the dorsal region; in the loins the curvature is again convex ventrally, and in the sacrum and coccyx the reverse is the case. These curves add greatly to the springiness of the spine, and prevent the transmission of sudden jars.* The elastic cushions (intervertebral disks) placed between the bodies of the vertebræ also aid in protecting the delicate brain and the spinal cord from injury.

The intervertebral disks allow of a certain range of movement between each pair of vertebræ, so that the column as a

* Take a straight but tolerably flexible and elastic bar, as a lath or, better still, a thin steel rod. Hold it vertical, with one end resting on the floor, and give a smart blow on the upper end; the jar will be sudden and violent. Now bend the rod and hit it again; the jar will be much less, as the curved rod yields somewhat to the blow on its top.

whole may be bent in any direction. On the other hand, these pads and the ligaments so limit the movement that no

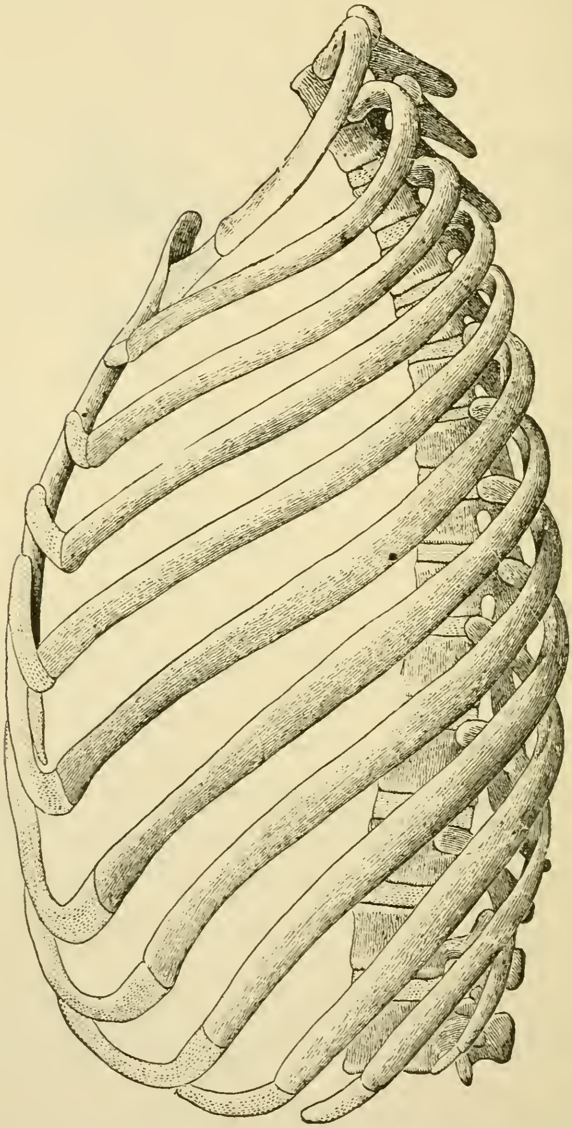


FIG. 15.—The ribs of the left side, with the dorsal and two lumbar vertebræ, the rib cartilages, and the sternum.

sharp bend which would compress or injure the spinal cord can occur at any point.

The sacral vertebræ are separate in infancy, but grow together firmly to give a solid support to the pelvic arch, which transmits the weight of the body to the lower limbs when we stand.

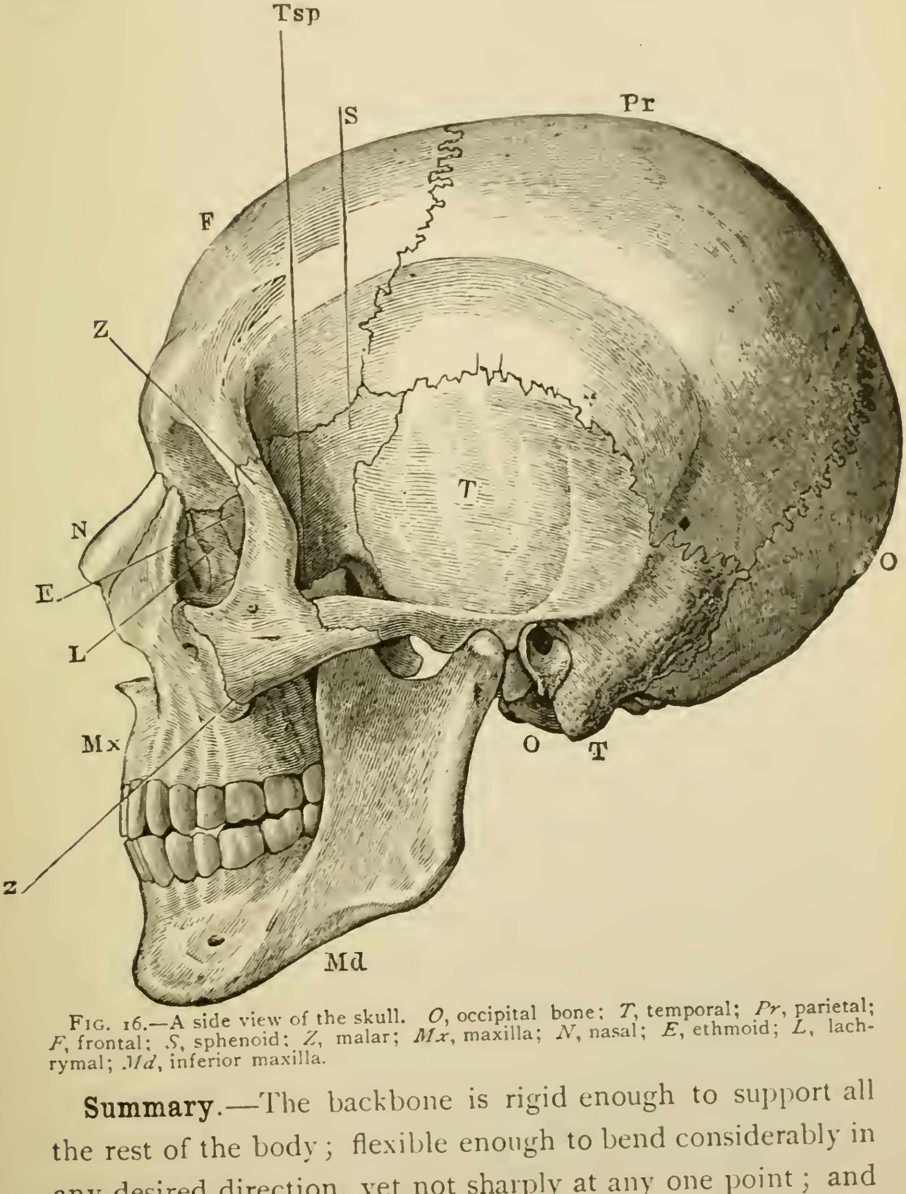


FIG. 16.—A side view of the skull. *O*, occipital bone; *T*, temporal; *Pr*, parietal; *F*, frontal; *S*, sphenoid; *Z*, malar; *Mx*, maxilla; *N*, nasal; *E*, ethmoid; *L*, lachrymal; *Md*, inferior maxilla.

Summary.—The backbone is rigid enough to support all the rest of the body; flexible enough to bend considerably in any desired direction, yet not sharply at any one point; and

elastic enough to destroy or greatly diminish any sudden jar or jerk which it may receive. It is one of the most beautiful pieces of mechanism in the body.

The Ribs are twenty-four in number, twelve on each side (Fig. 15). They are slender curved bones which embrace the sides of the chest and are attached at the dorsal end to the dorsal vertebræ. Ventrally each rib ends in a *costal cartilage;* the cartilages of the seven upper pairs are directly articulated to the sides of the breast-bone. The eighth, ninth, and tenth rib cartilages join the cartilages of the ribs above; the eleventh and twelfth are not attached to the rest of the skeleton at their ventral ends and hence are known as the *free* or *floating ribs.*

The Skull (Fig. 16) is composed of twenty-eight bones: eight of these form the *cranium* and are arranged to surround the brain and protect the deep parts of the ears; six lie inside the ears; and the remaining fourteen support the face, surround the mouth and nose, and (with the aid of some of the cranial bones) form the eye sockets.

The Cranium is a box whose thick floor (Fig. 1) continues anteriorly the partition which in the trunk separates the neural from the ventral cavity. On its under side (Fig. 20) are many small apertures for nerves and blood vessels to pass in or out, and one large opening, the *foramen magnum*, for the spinal cord.

The cranial bones (Fig. 16) are the following: 1. *The occipital bone*, *O*, which lies at the back of the skull and has in it the foramen magnum. 2. *The frontal bone*, *F*, which forms the forehead. 3. *The parietal bones*, *Pr*, two in number, which meet one another above the middle of the crown of the head, and form a large part of the roof and sides of the skull. 4. *The temporal bones*, *T*, one on each side,

which contain the corresponding ear cavities. 5. *The sphenoid bone*, which, with the occipital bone, forms the base of the skull, and sends out a wing, *S*, on each side. 6. *The ethmoid bone*, *E*, which forms the partition between the brain and nose chambers, and part of that between the nose and the eye socket.

The Facial Skeleton.—The majority of the face bones are in pairs, but two are single; one of these is the *lower jaw bone* or *mandible*, *Md*, Fig. 16; the other is the *vomer*, which forms part of the partition between the two nostrils.

The paired face bones are: 1. The *maxillæ* or *upper jaw bones*, *Mx*, which carry the upper teeth and form most of the hard palate separating the mouth from the nose. 2. *The palate bones*, which complete the bony palate, and lie in front of the opening (posterior nares) by which the air passes from the nasal chambers into the throat cavity (Fig. 20). 3. *The malar* or *cheek bones*, *Z*. 4. *The nasal bones*, *N*, roofing in the upper part of the nose. 5. *The lachrymal* or *tear bones*, *L*, small and thin, between the eye socket and the nose. 6. *The inferior turbinate or spongy bones*, which lie inside the nose, one on the outer side of each nostril chamber.

The Cranial Sutures.—All the bones of the skull, except the lower jaw bone, are immovably joined together. The edges of most of the cranial bones interlock in a manner similar to the dovetail joint of cabinet-makers. Each bone has notched edges which fit accurately into hollows of the adjacent bone; this kind of articulation (or *suture*) is well shown in Fig. 16.

Comparison of the Upper and Lower Limbs and their Supporting Arches.—The bones of the leg and arm have already been enumerated, but certain resemblances and differences between the two (Fig. 17) are worth noting. It is

clear that they correspond very closely to one another in general structure; the pectoral arch answers to the pelvic;

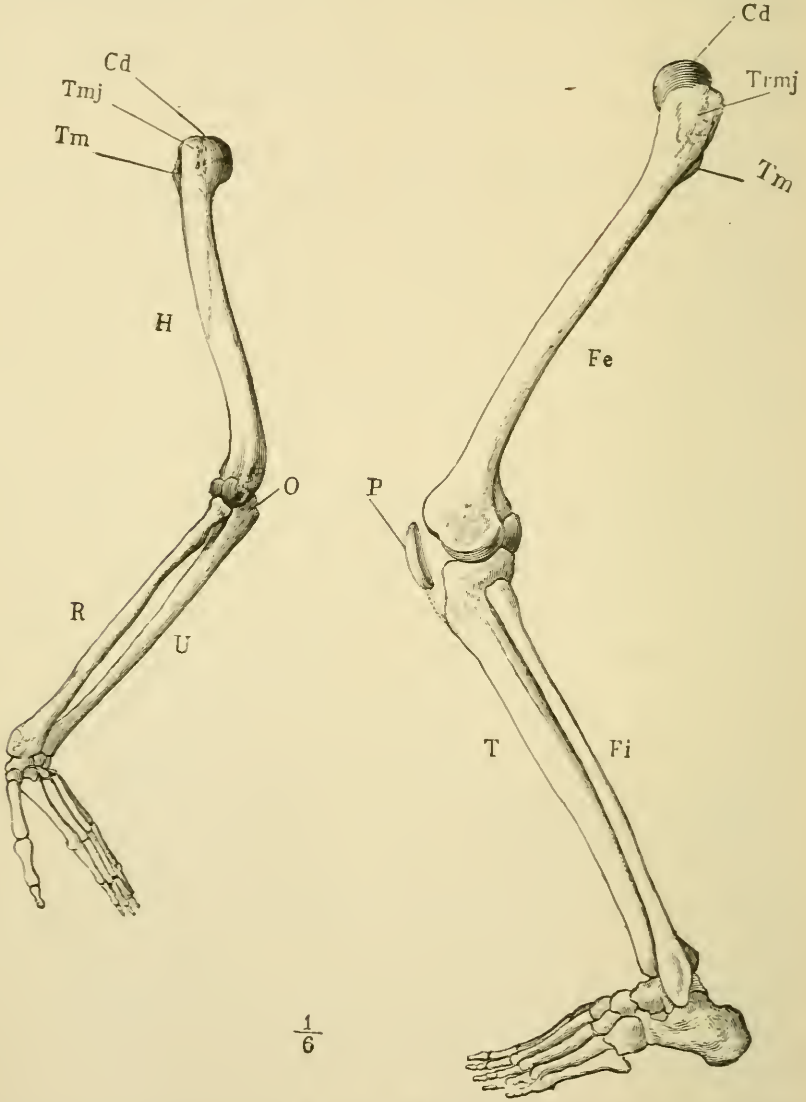


FIG. 17.—The skeleton of the arm and leg. *H*, the humerus; *Cd*, its articular head which fits into the glenoid fossa of the scapula; *U*, the ulna; *R*, the radius; *O*, the olecranon; *Fe*, the femur; *P*, the patella; *Fi*, the fibula; *T*, the tibia.

the humerus to the femur; the radius and ulna to the tibia and fibula; five metacarpal bones correspond to five meta-

tarsal, fourteen phalanges in the digits of the hand to fourteen in the digits of the foot; and elbow and wrist joints, to knee and ankle. There is, however, in the arm no separate

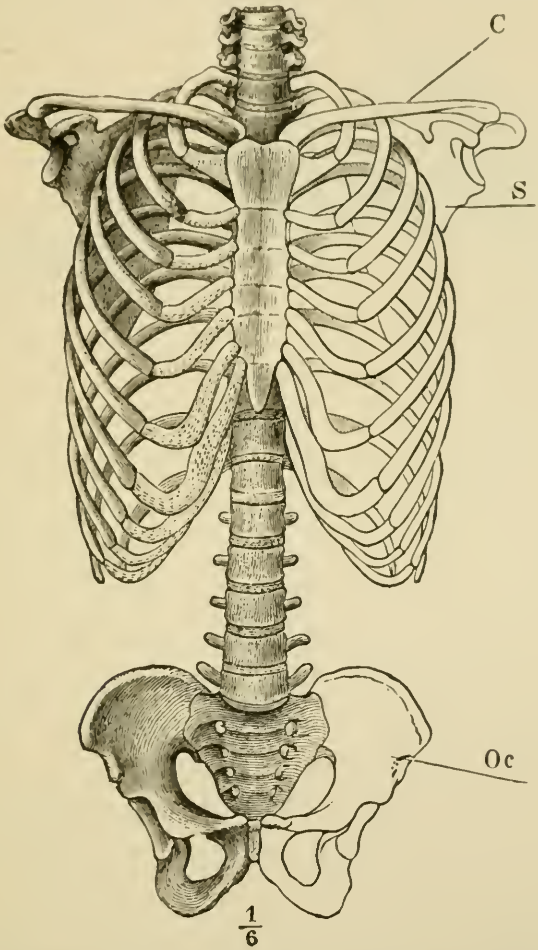


FIG. 18.—The skeleton of the trunk and the limb arches seen from the front. *C*, clavicle; *S*, scapula; *Oc*, innominate bone attached to the side of the sacrum dorsally and meeting its fellow at the ***pubic symphysis*** in the ventral median line.

bone at the elbow answering to the patella at the knee; but the ulna bears a bony process, *O*, which is in early life a separate bone and may be considered as corresponding to the patella. There are in the adult carpus eight bones, in the tarsus but

seven; here again we find, however, that originally the *astragalus, Ta* (Fig. 19), of the tarsus consists of two bones. The elbow joint bends ventrally and the knee joint dorsally.

When we compare the functions of the limbs greater differences appear. The arms have their parts light and movable to serve as prehensile organs; the lower limbs have their parts heavy and firmly knit together to carry the weight of the body. Accordingly we find the shoulder girdle, *C, S* (Fig. 18), attached to the axial skeleton only by the ventral ends of the collar bones, and hence it is free to make considerable movement, as in "shrugging the shoulders." The pelvic girdle, *Oc*, on the contrary, is firmly and immovably attached to the sides of the sacrum.

The socket on the outer end of the shoulder blade, which receives the upper end of the humerus to form the shoulder joint, is very shallow, and allows much freer movement than the deeper socket of the pelvis, into which the top of the femur fits.

If we hold one humerus tightly and do not allow it to rotate, we can still move the forearm bones so as to turn the palm of the hand up or down; no such movement is possible between tibia and fibula.

In the foot the bones are much less movable than in the hand, but are so arranged as to make an elastic arch (Fig. 19) springing from the rear end of the heel bone, *Ca*, to the anterior ends, *Os*, of the metatarsal bones. When we stand, the weight of the body rests on the articular surface (*Ta*) at the crown of the arch.

The toes are far less mobile than the fingers, the difference between great toe and thumb being especially marked. The thumb can be made to meet each of the finger tips, so that the hand can seize and manipulate very small objects,

whereas this power of *opposing* the great toe to the others is nearly absent in the foot of civilized man. In infants, and in savages who have never worn boots, the great toe is often movable, though it never acts so completely like a thumb as

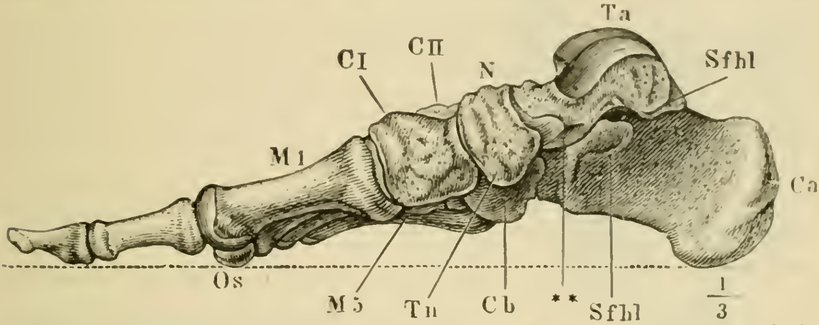


FIG. 19.—The bones of the foot. *Ca. Calcaneum*, or heel bone; *Ta*, articular surface for tibia on the *astragalus; Cb*, the cuboid bone.

it does in most apes, which use their feet for prehension nearly as much as their hands. Our own toes by practice can be made more movable; persons born without hands have learned to write and paint with the feet.

Peculiarities of the Human Skeleton.—Our power of maintaining an erect posture and of walking without the aid of the hands gives rise to interesting peculiarities in the structure of the human skeleton. In no other vertebrate is the division of labor between the anterior and posterior limbs carried so far; even the highest apes often use the hand in locomotion and the foot for prehension. As characteristic of man's skeleton we may note:

1. The skull is nearly balanced* on the top of the vertebral column (Fig. 20), so that but little effort is needed to keep the head erect. In four-footed beasts the skull is carried on the

* The balance is, however, not quite complete. When any one goes to sleep in an ill-ventilated lecture-room he is usually awakened by a sharp jerk downwards of his chin. Since the muscles concerned in holding the head erect have relaxed their vigilance, the greater weight of the front half of the skull exerts its effect.

front end of a horizontal backbone, and therefore needs special ligaments and considerable muscular effort to support it ; in apes the skull does not balance on the top of the spine, because the face is much heavier than the brain. Therefore to keep the head erect and look things straight in the face "like a man" is very fatiguing and the position cannot long be maintained. In men, on the contrary, the face bones are relatively smaller and the cranium larger, so that this position is maintained with ease.

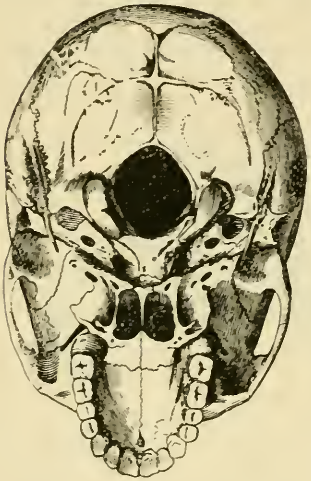


FIG. 20.—The base of the skull. The lower jaw has been removed. At the lower part of the figure is the hard palate forming the roof of the mouth and surrounded by the upper set of teeth. Above this are the paired openings of the posterior nares, and a short way above the middle of the figure is the large median *foramen magnum*, with the bony convexities (or *occipital condyles*) which articulate with the atlas, on its sides. It will be seen that the part of the skull behind the occipital condyles is about equal in size to that in front of them; in an ape the portion in front of the occipital condyles would be much larger than that behind them.

2. The human spinal column, when viewed from the front, is seen to widen gradually from the neck to the sacrum, and is, therefore, well fitted to sustain the weight of the head, upper limbs, etc. Its curvatures, which are peculiarly human, add greatly to its spring and elasticity.

3. The pelvis, to the sides of which the lower limbs are attached, is relatively broad in man, so that the balance of the trunk on the legs is more strongly maintained.

4. The lower limbs are proportionately much longer than the arms in man. This makes progression on them more rapid by allowing a longer stride, and also makes it difficult to go on "all fours" except by creeping on the hands and knees. The arms of some apes are as long as, and of others longer than, their legs.

5. The arched instep and broad sole of the human foot are very characteristic. Most beasts, as horses, walk on the tips of their toes, and the hoof is really a very big toe nail; others, as bears, place the heel on the ground to be sure, but have a less well-developed tarsal arch than man. The vaulted human tarsus, made up of a number of small bones, each of which can glide a little over its neighbors, but none of which can move much, is admirably calculated to break any jar which might be transmitted to the spinal column by the intermittent contact of the sole with the ground.* A well-arched instep is therefore rightly considered beautiful; it makes the gait easier and more graceful.

* A carriage spring consists of two curved elastic steel bars fastened together at their ends, with their concave sides turned towards one another. The axle of the wheel is attached to the middle of the lower bar, and the weight of the carriage bears on the middle of the upper. When the wheel jolts over a stone the jerk is transmitted to the elastic arches, which are each flattened a little, so that instead of a sudden jerk a gentle sway is transmitted to the carriage. The tarsal arch of the human foot acts like the upper half of a carriage spring.

CHAPTER IV.

THE STRUCTURE, COMPOSITION, AND HYGIENE OF BONES.

The Gross Structure of Bones.—Although the bones differ very much in shape, all are alike in microscopic structure and in chemical composition. When alive they have a bluish-white color, with a pinkish hue if blood is flowing through them; they possess considerable flexibility and elasticity; this may be best observed in a long slender bone, as a rib.*

To get a general idea of the structure of a bone we may select the humerus (Fig. 21). When fresh this is closely covered by a tough membrane, *the periosteum*, composed of connective tissue and containing many blood vessels. During the growth of the bone the periosteum deposits new bony tissue upon it and is concerned in its nourishment throughout life. When it is stripped off, the bone dies.† The periosteum covers the humerus except on its ends (*Cp*, *Tr*, *Cpl*) in the shoulder and elbow joints, where the bone is covered by a thin layer of gristle or cartilage. Very early in life the whole humerus consists of cartilage; this is after-

* The rib of a sheep or a rabbit when thoroughly boiled can be readily scraped clean and preserved, and serves admirably to show the flexibility and elasticity of bone.

† Cases have been recorded in which a considerable portion of a bone or even the whole bone has been removed during life, and the periosteum (left but slightly injured) has formed a new bone in place of the old.

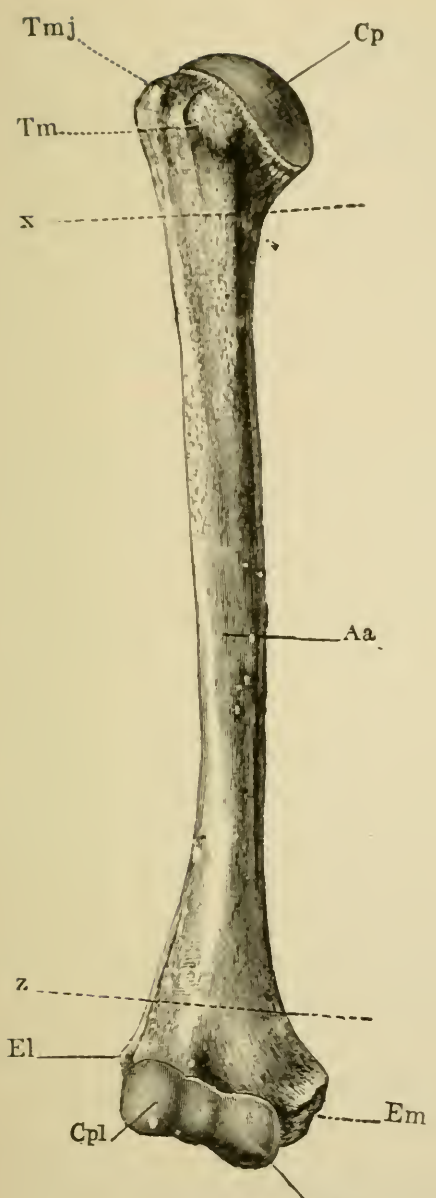


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FIG. 21.—The right humerus, seen from the front For description, see text.

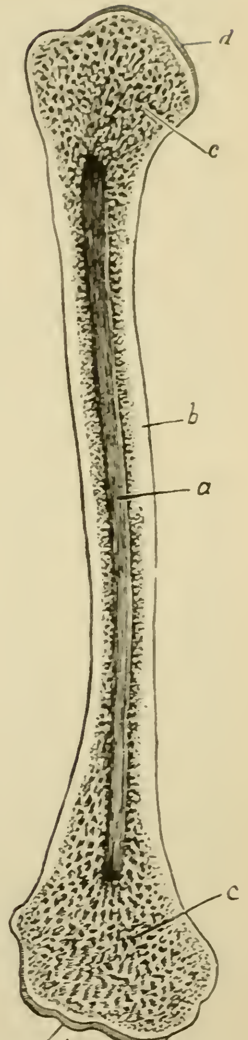

FIG. 22.—The humerus cut open. *a*, marrow cavity; *b*, hard bone; *c*, spongy bone; *d*, cartilage.

wards absorbed and replaced by bone, leaving only a thin layer of *articular cartilage* on each end.

The bone itself consists of an almost cylindrical middle portion or *shaft* (extending between the dotted lines *X* and *Z*) and two *articular extremities*. These extremities are enlarged to give a wider bearing surface in the joints, and also to provide space on which to attach the muscles which move the bone; the various knobs on the extremities and the rough patches on the shaft mark areas where muscles were fixed.

Internal Structure.—If the humerus is divided lengthwise, we find that its shaft is hollow; the space is known as the *medullary cavity*, and in life is filled with soft fatty marrow. Fig. 22 represents such a longitudinal section. We see that the marrow cavity extends nearly to the articular extremities; and that in these the bone has a loose, spongy texture, with the exception of a thin dense layer on the surface. In the shaft the compact outer layer is thick, whereas the spongy portion forms only a thin stratum next the medullary cavity.* To the unassisted eye the spongy (cancellated) bone appears made up of a trellis-work of thin bony plates which intersect in all directions and surround pin-head cavities. In these spaces there is found during life a substance known as the *red marrow*,† which is quite different from the yellow fatty marrow of the medullary cavity.

Why Bones are Hollow.—If the bones were solid and of their present size, they would be extremely heavy ‡ and un-

* These facts may readily be demonstrated by sawing in two lengthwise the bones out of a leg of mutton.

† The red marrow forms red blood corpuscles.

‡ Many of the bones of birds are thin-walled tubes of dense bone: the central cavity contains air and no marrow, and communicates by tubes with the lungs. Examine the humerus of a pigeon or a rooster.

necessarily strong for the common purposes of life; if they were solid and of their present weight, they would not give sufficient surface for the attachment of muscles, and would be easily broken. It is a well-known principle in practical mechanics that a tube will bear a greater strain than a solid rod of the same length and amount of material; hence iron pillars are cast hollow, for if solid they would be enormously heavier without a proportionate increase in strength. Take a glass tube and a glass rod each of the same length and weight; support each at its ends and hang weights on the middle until it breaks: the tube will be found to bear a much greater strain before breaking. We see an application of this same principle in the hollow stalks of grass, wheat, and barley and in the frames of bicycles.

Varieties of Structure Found in Different Bones.—Bones which, like the humerus and femur, present a shaft and articular extremities are called *long bones;* other examples are tibia and fibula, radius and ulna, metacarpal and metatarsal bones, and the phalanges of fingers and toes. *Tabular bones* form thin plates, like those of the roof of the skull, and the shoulder blades. *Short bones* are rounded or angular, and not much longer in one diameter than another, as the carpal and tarsal (Fig. 19) bones. *Irregular bones* include all which do not fit well into any of the above classes; they usually lie in the middle line of the body and are divisible into similar right and left halves; the vertebræ are good examples.

All bones are covered by periosteum except where they enter into the formation of a joint, but in the human body only the long bones possess a medullary cavity containing yellow marrow. The rest are filled up by spongy bone, covered by a thin layer of ivory bone, and have red marrow in their spaces.

The Histology of Bone.—The microscope shows that compact bone is really porous, and differs from spongy bone only in the fact that its cavities are much smaller, and the hard bony plates between them thicker. If a thin transverse section of the shaft of long bone (Fig. 23) is examined with a microscope magnifying about twenty diameters, even its densest part will show numerous openings which become gradually larger near the medullary cavity and pass insensibly into the spaces of the spongy bone around it. These openings

FIG. 23.—*A*, a transverse section of the ulna, natural size, showing the medullary cavity. *B*, the more deeply shaded part of *A* magnified twenty diameters.

are the cross-sections of tubes known as the *Haversian canals*, the majority of which run through the bone in the direction of its long axis and are united by numerous cross branches. The

outermost Haversian canals open on the surface of the bone beneath the periosteum, where they receive blood vessels which pass through them to convey materials for the bone's growth and nourishment.

Around each Haversian canal is a series of plates or *lamellæ* which, with the canal, form an *Haversian system*; the entire bone is made up of a large number of such systems, with the addition of some lamellæ which lie in the corners between them, and some which have been formed by the periosteum on its outer surface. In the spongy bone the Haversian canals are very large, and contain red marrow as well as blood vessels, with only a few lamellæ around each.

FIG. 24.—A small piece of bone, ground very thin and highly magnified.

If a bit of bone is still more magnified (Fig. 24) we find that very small cavities called lacunæ lie between the lamellæ; from each lacuna radiate many extremely fine tubes, the *canaliculi*, so that it looks like a small animal with a great many legs. The innermost canaliculi open into the Haver-

sian canal of the system to which they belong, and those of various lacunæ communicate with one another, so that a set of passages is provided through which liquid which transudes from the blood vessel in the Haversian canal can ooze through the bone.

In a living bone a nucleated cell, or bone corpuscle, lies in each lacuna. These are the remnants of those cells which built the bone, by making intercellular substance; each one builds a sort of skeleton around itself which adheres to the skeletons of the others to form the whole bone.

Chemical Composition of Bone.—Apart from the bone corpuscles and the soft contents of the Haversian canals and of the spaces of the cancellated bone, the hard bony substance proper is composed of animal and mineral matters so intimately combined that the smallest distinguishable bit of bone contains both. The mineral matters give the bone its hardness and rigidity, and form about two thirds of its weight when dried. They may be removed by soaking the bone in diluted hydrochloric acid,* and the animal or organic part of the bone is then left as a tough, flexible mass, which retains perfectly the shape of the original bone.

When the bone is boiled in water, the greater part of the animal portion is turned into *gelatine* (or glue) and is dissolved in the water. Most of the gelatine which we buy in the shops is obtained by boiling fresh bones in a closed vessel under high pressure; in this way, the water becomes much hotter than when boiled in the air, and dissolves out the gelatine

* Add a couple of ounces of hydrochloric acid to a pint of water and place a sheep's rib in the mixture for a day or so, after having previously scraped the bone clean, and boiled it to get rid of the fat. It will be found so flexible that a knot may be tied in it; the specimen may be preserved in strong brine or dilute alcohol from year to year for exhibition to a class.

more quickly. When a shin of beef is used to make soup the bones are put in as well as the flesh, and the whole is kept boiling for hours to extract the gelatine. The animal matter of bone gives it toughness and elasticity.

The earthy portion may be obtained free from the animal by calcining a bone in a bright fire. The residue is a white and very brittle mass, which retains perfectly the shape of the original bone. It is readily powdered and then forms bone ash, which consists chiefly of the phosphate and carbonate of calcium; most of the phosphorus of commerce is obtained from it. If the burning be imperfect the animal matter is charred but not altogether burnt away, and a black mass, known as animal charcoal or "bone black," is left.

Hygiene of the Bony Skeleton.—In early life the animal matter of the bones is present in larger proportion than later; hence the bones of children are tougher, more pliable, and not so easily broken. The bones of a young child are tolerably flexible and are capable of being distorted by a long continued severe strain. For this reason it is important that a child be made to sit straight, when writing or drawing, to avoid the risk of producing a lateral curvature of the spinal column; and children should not be made to sit up during the first year or to walk too early, as their bones are not rigid enough to bear the weight of the body. The readiness with which bones yield to prolonged pressure in early life is well illustrated by the distorted feet of Chinese ladies, and by the extraordinary forms (Fig. 25) which some races produce in their skulls by tying boards or bandages on the heads of the children. A distorted foot, even in the United States, is no uncommon thing in these days of tight boots and high heels. The latter are especially bad, for, instead of allowing the arch of the foot to support squarely

the weight of the body, they tilt the arch forward and throw the weight upon the toes, which are thereby squeezed into the front of the boot. This not only crushes the toes and leads to deformities, corns, and bunions, but makes the gait stiff, inelastic, and ungraceful.

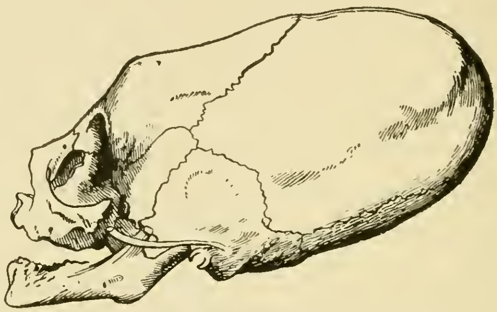

FIG. 25.—Skull of a child of the tribe of Chinook Indians (inhabiting the neighborhood of the Columbia River), distorted by tight bandaging so as to assume the shape considered elegant and fashionable by the tribe.

In advanced life the animal matter of the bones is present in deficient amount, and hence they are brittle and easily broken.

An infant grows rapidly and hence needs food containing phosphate of lime, which is the chief mineral constituent of bone. Of all common articles of diet, milk contains most phosphate of lime: this is one great reason of its value as a food for children.

Fracture.—A break in a bone is called a *fracture;* when it is a clean break the fracture is *simple;* when the bone is more or less broken into bits on each side of the break the fracture is *comminuted;* when the soft parts also are lacerated, so that there is an opening from the skin to the broken bone, the fracture is *compound.*

If a bone is broken the muscles attached to it tend to pull its ends out of place; hence it requires to be "set," and

then kept in position by splints or bandages; this frequently needs much skill and a thorough knowledge of the anatomy of the body. A surgeon should be summoned at once, as the parts around the break commonly swell very rapidly and make the exact nature of the fracture hard to detect, and the replacment of the displaced ends difficult.

CHAPTER V.

JOINTS.

The Movements of the Body are brought about by means of the soft reddish flesh known as the *muscles*, which are familiar to all in the lean of meat.* Muscles have the power of contracting with considerable force; they pull their ends toward one another and swell out in the middle (Fig. 29); in other words, they become shorter and thicker. With few exceptions, each muscle is attached by its ends to two bones † and overlaps the joint between them. When the muscle shortens, or *contracts*, it produces movement at the joint. The bones, joints, and muscles thus form the chief motor mechanism of the body.

Joints.—Articulations which permit of movement by the gliding of one bone on another are called *joints;* all are constructed on the same general plan, though the range and

* In many animals muscles kept most constantly in use are much redder than others, as, for example, the leg muscles of a chicken, which are redder than those of the wings and breast, and as the coloring matter is turned brown by heat, they form the "dark meat" after cooking; in birds which fly a great deal the breast muscles (which move the wings) are also dark. The heart, which is a muscle always at work, is deep red, even in fishes, most of whose muscles are pale.

† As an example of a muscle not attached to the skeleton, we may take the *orbicularis oris*, which forms a ring around the mouth opening, beneath the skin of the lips; when it contracts it closes the mouth, or if it contracts more forcibly purses out the lips. The *orbicularis palpebrarum* forms a similar ring around the eye opening, and when it contracts closes the eye.

direction of movement permitted differ in different joints. As an example we may take the hip joint, a section of which is represented in Fig. 26.

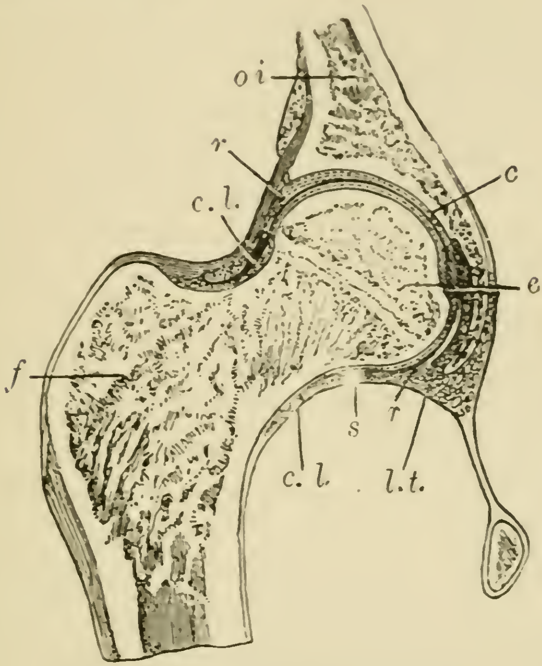

FIG. 26.—Section through the hip joint.

On the outer side of the os innominatum (*oi*. Fig. 26) is a deep hollow, *the acetabulum*, which receives the upper end of the femur. The acetabulum is lined by a thin layer of cartilage (*c*) with an extremely smooth surface, and its cavity is also deepened by a cartilaginous rim (*r*). The upper end of the femur (*f*) consists of a nearly spherical head, borne on a neck; this head is covered by cartilage, and rolls smoothly in the acetabulum like a ball in a socket.

Ligaments bind the ends of the bones together to prevent their displacement; they are composed of connective tissue, are extremely pliable but cannot be stretched, and are very tough and strong. One is the *capsular ligament* (*c. l.*), which encloses the joint in a bag; another is the *round ligament*

(*l. t.*), Fig. 26, which passes from the rim of the acetabulum along a groove in the bone to the centre of the round head of the femur.

Covering the inside of the capsular ligament and continued back to the edge of the cartilage of the head of the femur is the very thin *synovial membrane* (*s*), composed of a layer of flat cells. This pours into the joint a small quantity of *synovial liquid*, which resembles in consistency the white of a raw egg, and plays the part of oil in a machine by lubricating the joint and enabling it to move smoothly and with little friction.

In its natural state the synovial membrane lies so that there is practically no cavity left in the joint. The joint surfaces are held in close contact, not by the ligaments (which are much too loose and serve mainly to prevent such excessive movement as might roll the femur out of its socket), but by the many strong muscles which pass between pelvis and thigh bone and hold both firmly together. In addition, the pressure of the atmosphere is transmitted by the skin and muscles to the exterior of the air-tight joint, and helps to keep its surfaces together. If all the muscles are cut away from around the hip joint of a dead body, it is found that the head of the femur is still held in its place by the pressure of the air so firmly that the weight of the limb will not draw it out; but if the air is let into the joint by cutting into the cavity, the thigh bone falls as far out of place as the ligaments will let it.

In all joints we find the same essential parts: bones, articular cartilages, synovial membrane, synovial liquid, and ligaments.*

Ball and Socket Joints.—Such a joint as that at the hip

* The structure of joints can be readily seen in those of a fresh calf's or sheep's foot. The synovial membrane is so thin and so closely adherent to the parts it lines that a microscope is needed for its demonstration; but all the other parts are readily made out.

is called a ball and socket joint, and allows a greater variety of movement than any other. The thigh can (1) be *flexed*, that is, bent so that the knee approaches the chest, and (2) *extended* or straightened again; it can (3) be *abducted* so that the knee is moved away from the middle line of the body, and (4) *adducted* or brought back again; the limb can also (5) be *circumducted*, i.e., with knee and ankle held rigid, the whole leg is swung round to describe a cone, of which the apex is at the hip joint; and finally (6) *rotated*, i.e., the whole limb rolled to and fro on its long axis. All ball and socket joints allow these movements to a greater or less extent.

Another important ball and socket joint is at the shoulder between the upper end of the humerus and the hollow (*glenoid fossa*) near the upper outer corner of the shoulder blade. The glenoid fossa being much shallower than the acetabulum, the range of movement possible at the shoulder is greater than at the hip joint.

Hinge Joints.—In this form the bony cavities and projections are not spherical, but are grooved and ridged so that one bone can glide over the other in one plane only, to and fro, like a door on its hinges.

The knee is a hinge joint; it can only be bent and straightened, or *flexed* and *extended*. Between the phalanges of the fingers we find also hinge joints; another is found between the lower jaw and the cranium, allowing us to open and close the mouth. The latter is not, however, a perfect hinge joint; it permits also slight lateral movements, and a gliding motion by which the lower jaw can be thrust forward so as to bring the lower range of teeth outside the upper.*

* The object of these minor movements is to allow us to *chew* our food; in carnivora, as cats, which bite but do not chew, the lower jaw forms a perfect hinge joint with the cranium.

Pivot Joints.—In this form one bone rotates about another. A good example is found between the first and second cervical vertebræ (Figs. 13, 14). The odontoid process of the axis reaches up into the neural arch of the atlas, and is kept in place there by the transverse ligament, which does not let it press against the spinal cord. It forms a pivot around which the atlas rotates, carrying the skull with it when we turn the head to right or left.

A more complicated kind of pivot joint is found in the forearm. Lay the forearm and hand flat on a table, palm uppermost (supination): the radius and ulna are parallel. Without moving the shoulder joint at all turn the hand over so that its back is upward (pronation): the radius, carrying the hand, crosses over the ulna* (Fig. 27, A).

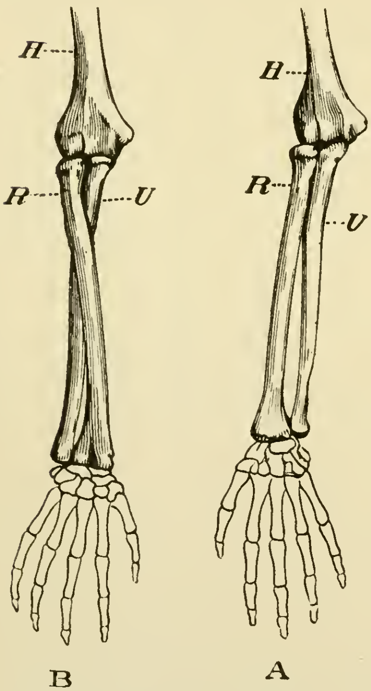

FIG. 27.—A, arm in supination; B, arm in pronation. *H*, humerus; *R*, radius; *U*, ulna.

The lower end of the humerus (Fig. 21) has a large articular surface; on the inner two thirds of this, *Tr*, the ulna fits, and the grooves and ridges of the bones interlock to form a hinge joint, allowing us only to bend or straighten the elbow joint. The radius fits on the rounded outer third, *Cpl*, and rotates there when the hand

* The movements and positions of the bones throughout the forearm and elbow joint may be observed by means of deep pressure with the fingers of the other hand.

is turned over, the ulna forming a fixed axis around which it moves.

Gliding Joints as a rule permit of but little movement. Examples are found between the closely packed bones of the carpus and of the tarsus (Fig. 19), which slide a little over one another when subjected to pressure.

Dislocations.—When a bone is displaced at a joint or *dislocated*, the ligaments are more or less torn and other surrounding soft parts injured. This generally leads to inflammation and swelling, which make it difficult to find out in what direction the bone has been displaced, and also greatly add to the difficulty of replacing it, or, in surgical language, of *reducing the dislocation*. The muscles attached to it are, moreover, apt to pull the dislocated bone more and more out of place. In most cases the reduction of a dislocation can only be attempted with safety by one who knows the forms of the bones and possesses sufficient anatomical knowledge to recognize the direction of the displacement.*

A Sprain is an injury to a joint, accompanied by straining, twisting, or tearing of the ligaments, without dislocation of the bones. A sprained joint should as a rule get immediate and complete rest, continued for weeks if necessary; if there be much swelling or continued pain, medical advice should be obtained. Perhaps a greater number of permanent injuries result from neglected sprains than from broken bones.

* Dislocations of the fingers can usually be reduced by strong pulling, aided by a little pressure on the parts of the bones nearest the joint. The reduction of a dislocation of the thumb is much more difficult, and can rarely be accomplished without skilled assistance.

CHAPTER VI.

THE MUSCLES.

The Muscles of the human body are more than five hundred in number; they vary much in size, from tiny ones attached to the bones of the ear to that on the front of the thigh (29, Pl. II), which passes from the pelvis to the tibia and is eighteen inches or more in length. Whatever their size, muscles have a similar structure and the same properties; their variety, forms, and sizes depend on the work they have to do. In addition to their primary function of moving the body the muscles give it roundness and shapeliness; they also help to enclose cavities, as the abdomen and the mouth; and they hold bones together at joints.

The Parts of a Muscle.—In its commonest form a muscle consists of a soft red middle part, called its *belly*, which tapers towards each end, where it passes into one or more dense, white, inelastic cords (*tendons*), made of connective tissue, which attach the muscle to parts of the skeleton.* In Fig. 28 are shown

* The parts of a muscle may readily be seen in that which forms the calf of a frog's leg. Put a teaspoonful of ether in a quart of water, immerse a frog in it, and cover the vessel. In a minute the animal will be quite insensible; its head can then be cut oft and its spinal cord destroyed by running a pin along it, without causing the animal any pain. Now make circular cuts through the skin at the top of the thighs and then peel the skin off like a pair of hose: it will come quite easily except about the knee joint, where it may be necessary to divide carefully one or two tough bands. On the skinned leg many muscles will be observed, and the long slender tendons which run to the toes. The calf muscle will be seen to end below in a strong tendon near the heel. If this be divided and the

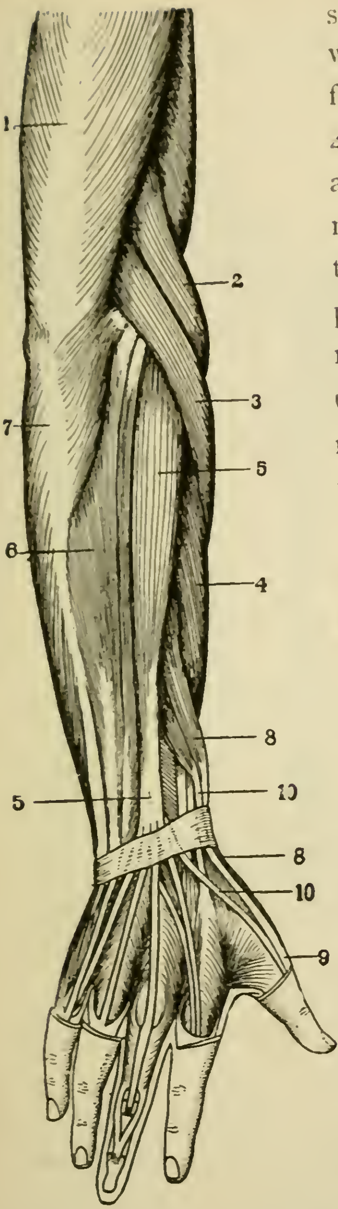

FIG. 28.—The muscles on the back of the hand, forearm, and lower half of the arm, as exposed on dissecting away the skin.

some of the muscles of the arm. It will be seen that some (1, 2, 3) pass from arm to forearm: others (7, 6, 5, 4, 8, 9) start from the forearm bones and pass to the bones of the hand; near the wrist they end in slender tendons, which are bound down into place by a stout cross-band of connective tissue. The skin has been dissected away from the back of the middle finger to show the endings of tendons on its phalanges.

The belly of a muscle is its working part; it receives nerves which when excited cause it to contract. In so doing it pulls on the tendons, and they transmit the pull to the parts to which they are attached.

The tendons are often quite long, as for example that of the common extensor muscles of the fingers (5, Fig. 28), whose belly is in the upper half of the forearm, but whose tendon, dividing above the wrist, is distributed to the joints of the fingers. The muscles which straighten the thumb (8, 9, and 10) are also seen to have long slender tendons. This arrangement makes the limbs light and slender.

muscle turned upwards, it will be found to have at the upper end of its thick rounded belly a pair of short tendons.

Some muscles pass over two joints and can produce movement at either; the *biceps* of the arm, fixed above to the

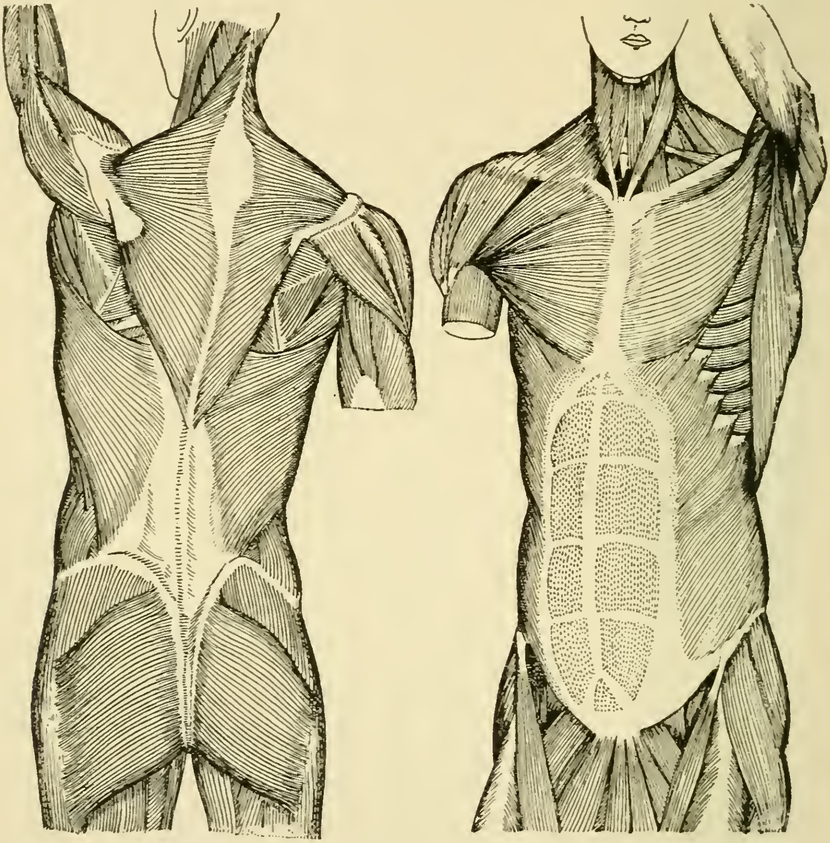

FIG. 29.—Back view of the muscles of the trunk
FIG. 30.—Front view of the muscles of the trunk.

scapula and below to the radius, can produce movement at either the elbow or the shoulder joint.

The shortening of a muscle when it contracts is shown by the movement which it causes; the thickening and hardening may be seen and felt on the biceps in front of the humerus when the elbow is bent, or in the ball of the thumb when it is moved so as to touch the little finger. The swelling and hardening of a contracted muscle are daily illustrated when one schoolboy invites another to feel his "biceps."

The Origin and Insertion of Muscles.—That part of the skeleton to which the inner (i.e., nearer the centre of the body) end of the muscle is attached is called its origin; that to which the outer is attached is called its insertion. Ordinarily, the origin is the less movable end. This may be seen in the arm, where we find that when the belly of the muscle

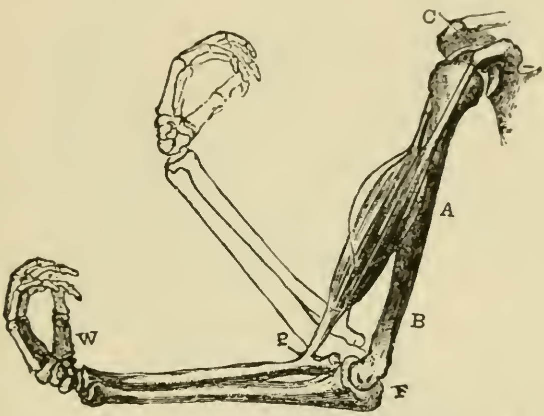

FIG. 31.—The biceps muscle and the arm bones, to illustrate how, under ordinary circumstances, the elbow joint is flexed when the muscle contracts.

contracts and pulls on its tendons, the result is commonly that only the forearm (insertion) is moved, the elbow joint being bent as shown in Fig. 31; the shoulder (origin) is firm and serves as a fixed point. The distinction is, however, only relative: if the radius were held immovable the muscle would move the shoulder toward the radius, instead of the radius toward the shoulder; as, for example, in going up a rope "hand over hand."

Varieties of Muscles.—Many muscles have the simple typical form of a belly tapering toward each end, as *A*, Fig. 32; others divide at one end, and are called two-headed or *biceps* muscles, and some are even three-headed or *triceps* (back of upper arm). On the other hand, some muscles have no tendon at one end, the belly itself being attached to the

bone; a few have no tendon at either end. Sometimes a tendon runs along the side of a muscle, and the fibres of the latter are attached to it obliquely (*B*, Fig. 32); such a muscle is called *penniform* or featherlike, from a fancied resemblance to the vane of a feather; or a tendon may run down the middle of the muscle (*C*), which is then called *bipenniform*. Sometimes a tendon is found in the middle of the belly as well as at each end (Fig. 33); such a muscle is called *two-bellied* or *digastric*. Running along the front of the abdomen, from the pelvis to the chest, on each side of the middle line, is a long muscle, *the straight muscle of the abdomen (rectus abdominis)*; it is *polygastric*, consisting of four bellies separated by short tendons.

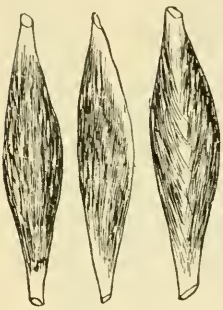

FIG. 32.—Diagrams illustrating, *A*, typical muscle with a central belly and two terminal tendons; *B*, a penniform muscle; *C*, a bipenniform muscle.

Many muscles are not rounded, but form wide, flat masses, as those which lie beneath the skin on the sides of the abdomen.

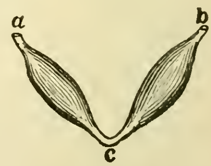

FIG. 33.—A digastric muscle.

How the Muscles are Controlled.—Most of the muscles of the body are paired, that is, they have corresponding muscles upon the opposite side.* The muscles are attached to the bones in such a way as to cause motion in all directions permitted by the joint. Thus some muscles oppose others, as, for example, the biceps muscle (Fig. 31), which lies in front of the humerus and bends the elbow joint, antagonizes the triceps muscle, which lies behind the arm bone and extends the elbow; when the biceps contracts the triceps relaxes, and *vice versa*. This orderly working is carried out by means of the

* The single muscles cross the middle line and are made up of similar right and left halves; examples are orbicularis oris and the diaphragm.

brain and spinal cord, which, through the nerves, govern the muscles and regulate their activity. In convulsions these controlling organs are out of gear, and the muscles are excited to

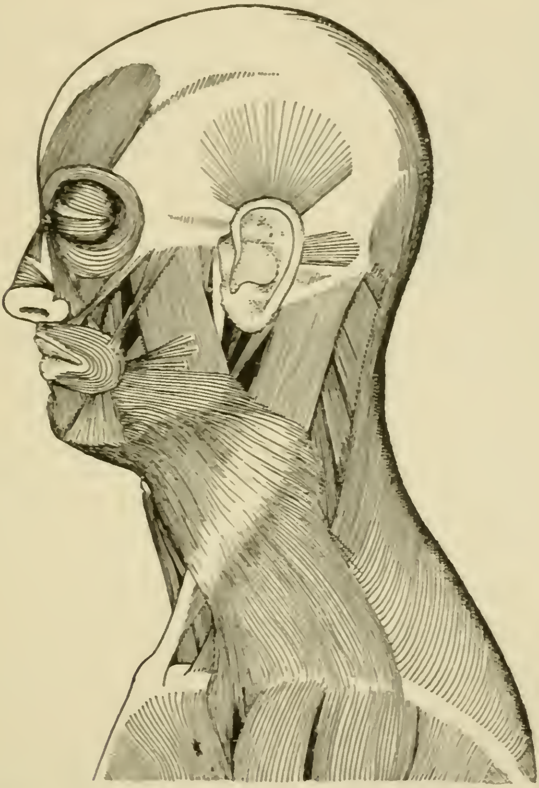

FIG. 34.—Side view of the muscles of the face and neck.

contract in all sorts of irregular and useless ways ; antagonists pulling against one another at the same moment cause the whole body to become rigid.

The Gross Structure of a Muscle.—Each muscle is an organ composed of several tissues. Its essential constituent is numbers of striped fibres constituting *striped muscular tissue.* These are supported and protected by connective tissue, intertwined with blood and lymph vessels which convey nour-

ishment and carry off waste matters, and penetrated by nerves which govern their activity.

A loose sheath of connective tissue, *the perimysium*, envelops the whole muscle in a sort of case; from it partitions run in and subdivide the belly of the muscle into bundles or *fasciculi* which run from tendon to tendon, or the whole length of the muscle when it has no tendons. The coarseness or fineness of meat depends on the size of these fasciculi, which may be readily seen in a piece of boiled beef. In good carving, meat is cut across the fasciculi, or "across the grain," as it is then more easily broken up by the teeth; the polygonal areas seen on the surface of a slice of beef are cross sections of the fasciculi. The larger fasciculi are subdivided by fine partitions of connective tissue into smaller (Fig. 35), each consisting of a few *muscular fibres* enveloped in a close network of minute blood vessels. Where a muscle tapers the muscle fibres in the fasciculi are less numerous, and when a tendon is formed they disappear altogether, leaving only the connective tissue.

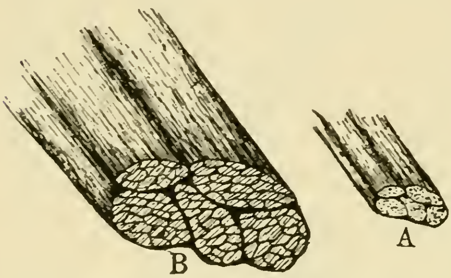

FIG. 35.—A small bit of muscle composed of four primary fasciculi. *A*, natural size; *B*, the same magnified, showing the secondary fasciculi of which the primary are composed.

Histology of Muscle.—*The striped muscular tissue*, which gives the muscle its power of contracting, is found when examined by the microscope to be made up of extremely slender muscle fibres, each about one inch in length, but most of them less than $\frac{1}{500}$ of an inch across.

Each muscle fibre has externally a thin sheath or envelope, the *sarcolemma*, which envelops the contracting part of the

fibre. This latter is soft and almost semi-fluid ; under a microscope it is seen to present a striped appearance, as if made up of alternating dimmer and brighter transverse bands (Fig. 36). After death the contents of the fibre solidify and death-stiffening results ; at the same time the fibre often splits up into a number of very fine threads or *fibrillæ*, which were formerly regarded as true constituents of the living muscular fibre.

The contraction of a voluntary muscle, as the calf muscle of the leg of a frog, is very rapid, as the entire twitch, including contraction and relaxation, takes but one tenth of a second.

FIG. 36.—A small piece of muscular fibre highly magnified. At *a* the fibre has been crushed and twisted so as to tear its contents, while the tougher sarcolemma, elsewhere so closely applied to the rest as to be invisible, remains untorn and conspicuous.

Plain Muscular Tissue. — The muscles hitherto spoken of are all more or less under the control of the will ; we can make them contract or prevent this as we choose ; they are therefore often called the *voluntary* muscles.* There are in the body other muscles

* No sharp line can be drawn between voluntary and involuntary muscles; the muscles of respiration are to a certain extent under the control of the will; any one can draw a long breath when he chooses. But in ordinary quiet breathing we are quite unconscious of their working, and even when we pay heed to it our control of them is limited; no one can hold his breath long enough to suffocate himself. Indeed, any one of the striped muscles may be thrown into activity, independently or even against the will, as we see in the "fidgets" of nervousness, and the irrepressible trembling of extreme terror. Functionally, when we call any muscle voluntary, we mean that it may be controlled by the will, but not that it necessarily always is so. Structurally, the heart occupies an intermediate place; its striped fibres resemble much more those of voluntary than of involuntary muscles, but its beat is not subject to the will.

whose contractions we cannot control, and which are hence called involuntary muscles; they are not attached to the skeleton directly, nor concerned in our ordinary movements, but lie in the walls of various hollow organs

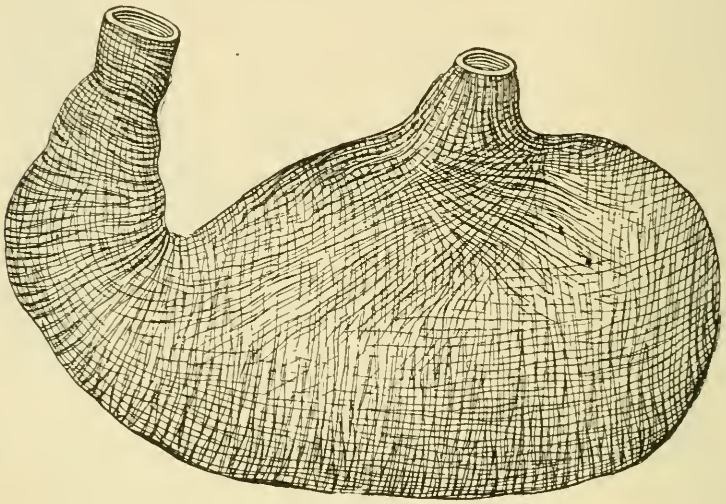

FIG. 37.—The muscular coat of the stomach.

of the body, as the stomach (Fig. 37), the intestines, and the arteries; by their contractions they move the contents of those cavities. Like the voluntary muscles, the involuntary consist of contractile elements, with accessory connective tissue, blood vessels, and nerves; but they are much shorter and smaller, and their fibres have a very different appearance under the microscope.* They are not cross striped, but are elongated cells united by a small amount of cementing material. Each cell (Fig. 38) is flattened and tapers off towards its ends; in its centre is a nucleus with one or two

* The smooth muscle fibres vary much in size in different organs. An average might be: Length $\frac{1}{500}$ in. to $\frac{1}{100}$ in.; breadth $\frac{1}{6000}$ in. to $\frac{1}{4000}$ in. They are thus seen to be about as long as the voluntary muscle fibres are broad.

nucleoli. The cells have the power of shortening in the direction of their long axes, but are very slow in their action.

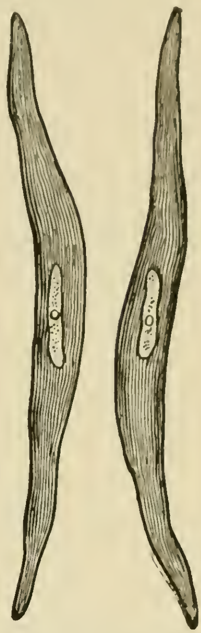

Fig. 38.—Unstriped muscle cells. (Highly magnified.)

Heart Muscle.—The muscular tissue of the heart is not under the control of the will ; it, however, is cross striped, and more like the voluntary than the ordinary involuntary muscle, though it differs from both. The contraction of the heart muscle is slower than that of voluntary muscles, but more rapid than that of the involuntary muscles.

Speaking generally, we may say that the movements necessary for the nutrition of the body are not left for us to look after, but are carried on by muscles which work involuntarily; the blood is pumped by the heart, and food churned in the stomach and passed along by the intestines, whether we think about it or not.

The Chemical Composition of Muscle.—Muscle contains about 75 per cent. of water and a considerable quantity of salts. Living, resting muscle is alkaline ; hard worked or dying muscle is acid. Its chief organic constituents are proteid or albuminous substances (p. 15), and of these the most abundant in a perfectly fresh muscle is *myosin*. Soon after death the myosin clots. Dilute acids dissolve myosin and turn it into syntonin, which used to be thought the chief proteid of muscle.

Beef Tea.—When lean meat is heated its myosin is converted into a solid insoluble substance much like the white of a hard boiled egg. Hence when a muscle is boiled most of its proteid is coagulated and stays in the meat in-

stead of passing out into the water. Even if beef be soaked first in cold water this is still the case, as myosin is not sol-

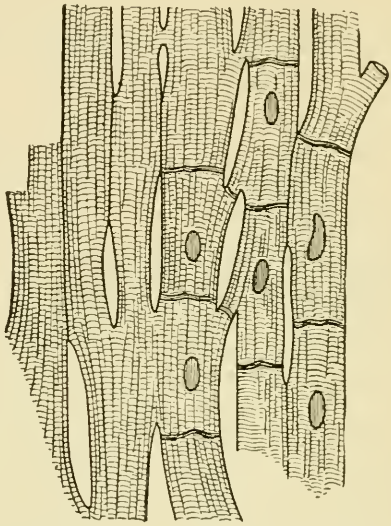

FIG. 39.—Fibres from the heart showing the striations and the junctions of the cells. Highly magnified.

uble in water.* It follows that beef tea as ordinarily made contains little but the flavoring matters and salts of the beef, and some gelatin dissolved out from the connective tissue of the muscle. The flavoring matters make it taste as if it were a strong solution of the whole meat, whereas it contains but a small proportion of the really nutritious parts, which are left behind in tasteless shrunken shreds when the liquor is poured off. Some things dissolved out of the meat make beef tea a stimulant to the nervous system and the heart, but its nutritive value is small, and it cannot be relied upon to keep up a sick person's strength for any length of time.

* To get over this difficulty, various methods of making beef tea have been suggested, in which the chopped meat is soaked an hour or two in strong brine or in very dilute muriatic acid. In these ways the myosin can be dissolved out of the beef; but the product has such an unpleasant taste that no one is likely to swallow it, and least of all a sick person.

EXPLANATION OF PLATE II.

A view of the muscles situated on the front surface of the body seen in their natural position. It must be understood that beneath these muscles many others are situated, which cannot be represented in the figure.

Muscles of the Face, Head, and Neck :

1. Muscle of the Forehead. This, together with a muscle at the back of the head, has the power of moving the scalp.
2. Muscle that closes the Eyelids. The muscle that raises the upper eyelid so as to open the eye is situated within the orbit, and consequently cannot be seen in in this figure.
3, 4, 5. Muscles that raise the Upper Lip and angle of the Mouth.
6, 7. Muscles that depress the Lower Lip and angle of the Mouth. By the action of the muscles which raise the upper lip, and those that depress the lower lip, the lips are separated.
8. Muscle that draws the Lips together.
9. Muscle of the Temple (Temporal Muscle).
10. Masseter Muscle. 9 and 10 are the two chief muscles of mastication, for when they contract the movable lower jaw is elevated, so as to crush the food between the teeth in the upper and lower jaws.
11. Muscle that compresses the Nostril. Close to its outer side is a small muscle that dilates the nostril.
12. Muscle that wrinkles the Skin of the Neck, and assists in depressing the lower jaw.
13. Muscle that assists in steadying the Head, and also in moving it from side to side.
14. Muscles that depress the Windpipe and Organ of Voice. The muscles that elevate the same parts are placed beneath the lower jaw, and cannot be seen in the figure.

Muscles that connect the upper extremity of the trunk. Portions of four of these muscles are represented in the figure, viz. :

15 Muscle that elevates the Shoulder. Trapezius Muscle.
17. Great Muscle of the Chest, which draws the Arm in front of the Chest (Great Pectoral Muscle).
18. Broad Muscle of the Back, which draws the Arm downwards across the back of the Body (Latissimus Dorsi).
19. Serrated Muscle, which extends between the Ribs and Shoulder blade, and draws the Shoulder forwards and rotates it, a movement which takes place in the elevation of the arm above the head (Serratus magnus).

At a lower part of the trunk, on each side, may be seen the large muscle which, from the oblique direction of its fibres, is called

20. Outer Oblique Muscle of the Abdomen.

Several muscles lie beneath it. The outline of one of these,

21. Straight Muscle of the Abdomen, may be seen beneath the expanded tendon of insertion of the oblique muscle. These abdominal muscles, by their contraction, possess the power of compressing the contents of the abdomen.

Muscles of the upper extremity :

16. Muscle that elevates the Arm (Deltoid Muscle).
22. Biceps or Two-headed Muscle (see also page 55).
23. Anterior Muscle of the Arm. This and the Biceps are for the purpose of bending the Forearm.
24. Triceps, or Three-headed Muscle. This counteracts the last two muscles, for it extends the Forearm.
25. Muscles that bend the Wrist and Fingers, and pronate the Forearm and Hand —that is, turn the Hand with the palm downwards. They are called the Flexor and Pronator Muscles.
26. Muscles that extend the Wrist and Fingers, and supinate the Forearm and Hand —that is, turn the hand with its palm upwards. They are called the Extensor and Supinator Muscles.
27. Muscles that constitute the ball of the thumb. They move it in different directions.
28. Muscles that move the Little Finger.

Muscles which connect the lower extremity to the pelvic bone : (Several are represented in the figure.)

29. Muscle usually stated to have the power of crossing one Leg over the other, hence called the Tailor's Muscle, or Sartorius; its real action is to assist in bending the knee.
30. Muscles that draw the Thighs together (Adductor Muscles).
31. Muscles that extend or straighten the Leg (Extensor Muscles). The muscles that bend the Leg are placed on the back of the thigh, so that they cannot be seen in the figure.

Muscles of the leg and foot :

32. Muscles that bend the Foot upon the Leg, and extend the Toes.
33. Muscles that raise the Heel—these form the prominence of the calf of the Leg.
34. Muscles that turn the Foot outwards.
35. A band of Membrane which retains in position the tendons which pass from the leg to the foot.
36. A short muscle which extends the Toes.

The muscles which turn the foot inwards, so as to counteract the last-named muscles, lie beneath the great muscles of the calf, which consequently conceal them. The foot possesses numerous muscles, which act upon the toes, so as to move them about in various directions. These are principally placed on the sole of the foot, so that they cannot be seen in the figure. Only one muscle, 36, which assists in extending the toes, is placed on the back of the foot.

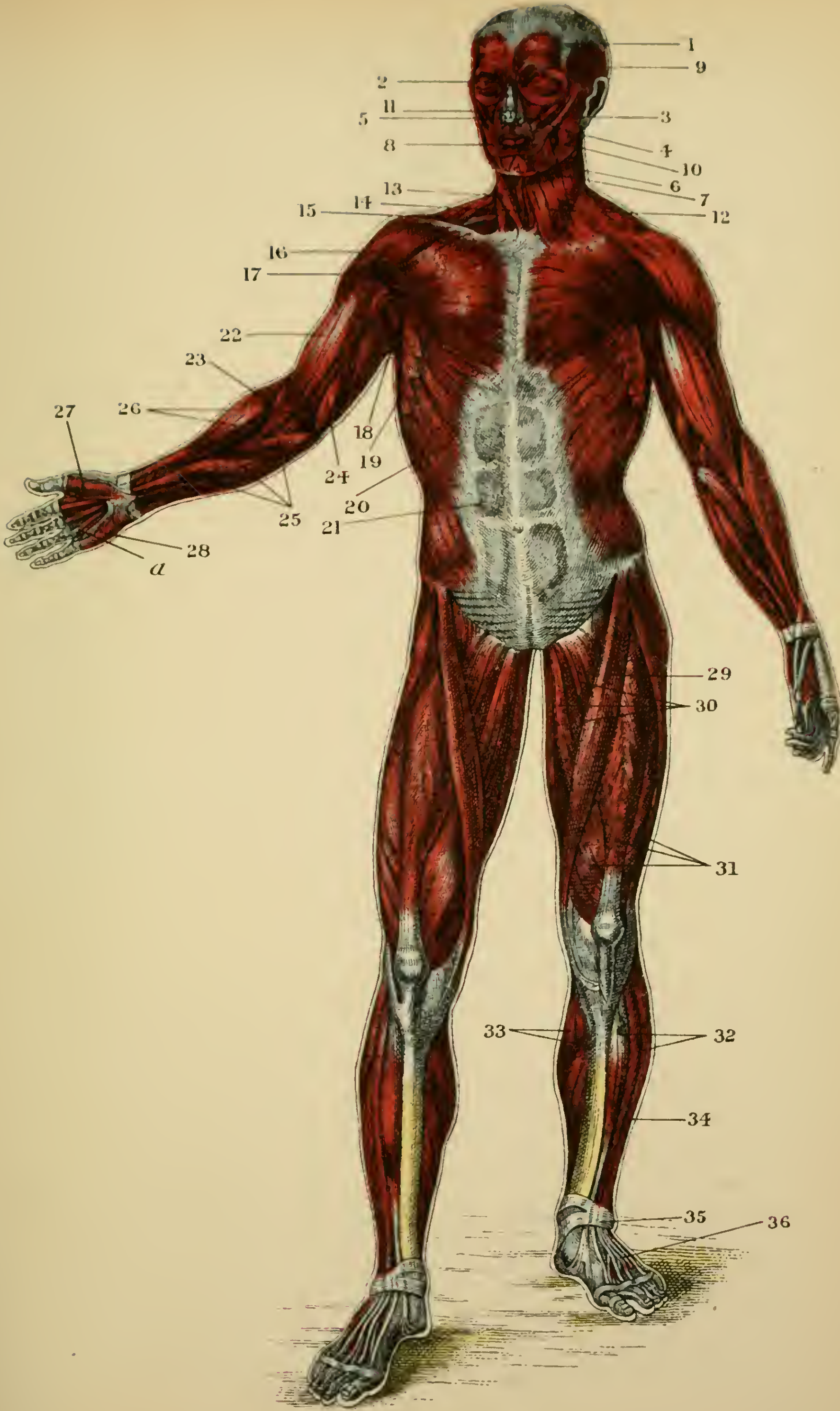

PLATE II.—THE SUPERFICIAL MUSCLES OF THE FRONT OF THE BODY.

Liebig's Extract of Meat is essentially but a concentrated beef tea; from its stimulating effect it is often useful to persons in feeble health, but other food should be given with it. It contains all the flavoring matters of the meat, and its proper use is for making gravies and flavoring soups; the erroneousness of the common belief that it is a highly nutritious food cannot be too strongly insisted upon, as sick persons may be starved on it.

Various *meat extracts* are now prepared by subjecting beef to chemical processes in which it undergoes changes like those experienced in digestion. The myosin is thus made soluble in water and uncoagulable by heat, and a real concentrated meat extract is obtained. Before relying on any one of them for the feeding of an invalid, it would, however, be well to insist on having a statement of its method of preparation, and then to consult a physician, or some one else who has the requisite knowledge, in order to ascertain if the method is such as might be expected to attain the end desired.

CHAPTER VII.

MOTION AND LOCOMOTION.

The Special Physiology of Muscles.—The distinctive property of muscular tissue (i.e., its power of contraction) is everywhere the same; but the uses of different muscles are varied by reason of their different positions and mechanical condition. Some are *muscles of respiration*, others *of swallowing;* some bend joints and are called *flexors*, others straighten them and are called *extensors*, and so on. The determination of the exact use of any particular muscle is known as its *special physiology*, as distinguished from its *general physiology*, or properties as a muscle. We may here consider the special physiology of the muscles concerned in standing and walking.

Levers in the Body.—In nearly all cases the voluntary muscles perform their work with the co-operation of the skeleton. When muscles move bones the latter are to be regarded as levers whose fulcra lie at the joint where the movement takes place. Examples of the three forms of levers recognized in mechanics are found in the human body.

Levers of the First Order.—In this form (Fig. 40) the fulcrum or fixed supporting point, *F*, lies between the weight to be moved and the moving power. The distance *PF* from the power to the fulcrum is called the power-arm of the lever, and the distance *WF* is the weight-arm. When

power-arm and weight-arm are equal (as in an ordinary pair of scales) no mechanical advantage is gained; to lift a

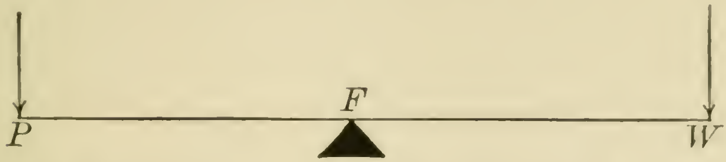

FIG. 40.—A lever of the first order. *F*, fulcrum; *P*, power; *W*, resistance or weight.

pound at *W*, *P* must be pressed down with a force slightly greater than a pound; and the end *W* will go up just as far as the end *P* goes down. If *PF* be longer than *WF*, then a small weight at *P* will balance a larger one at *W*, the gain being greater the greater the difference in the length of the arms, but the distance through which *W* is moved will be less than that through which *P* moves; for example, if *PF* is twice as long as *WF*, then half a pound at *P* will balance a pound at *W*, and a little more than half a pound laid on the end *P* will lift a pound on the end *W*, but *W* will only go up half as far as *P* goes down. On the other hand, if the weight-arm is longer than the power-arm there will be a loss in force, but a gain in the distance through which the weight is moved.

An example of levers of the first order is found in nodding movements of the head, the fulcrum being where the

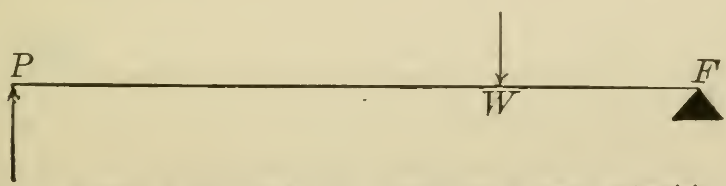

FIG. 41.—A lever of the second order. *F*, fulcrum; *P*, power; *W*, weight. The arrows indicate the direction in which the forces act.

occipital bone articulates with the atlas (Fig. 20). When the chin is raised the power is applied to the skull behind

the fulcrum by muscles passing from the spinal column to the back of the head; the resistance to be overcome is the excess in weight of the part of the head in front of the fulcrum over that behind it, and is not great, as the head is nearly balanced on the top of the spine. To let the chin drop does not necessitate any muscular effort.

The pull of the triceps to straighten the arm, and of the calf muscles in rising on the toes, are additional examples of the action of levers of the first class; the fulcrum in each case is at the joint, as it is in all the lever systems of the body.

Levers of the Second Order.—In this form of lever (Fig. 41) the weight or resistance acts between the fulcrum and the power. The power-arm, *PF*, is accordingly always longer than the weight-arm, *WF*, and so a comparatively weak force can overcome a considerable resistance. There is, however, a loss in rapidity and extent of movement, since it is obvious that when *P* is raised a certain distance *W* will be raised less. Levers of this class are practically unknown in muscular action.

Levers of the Third Order.—In these (Fig. 42) the power is applied between the fulcrum and the weight; hence the power-arm, *PF*, is always shorter than the weight-arm,

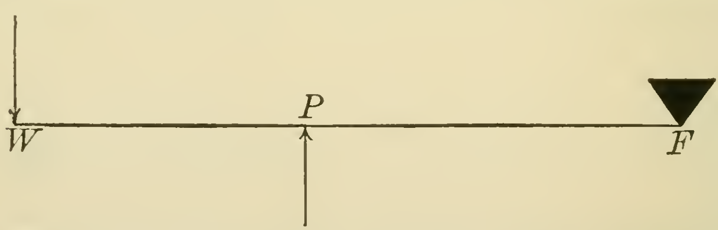

FIG. 42.—A lever of the third order. *F*, fulcrum; *P*, power; *W*, weight.

WF. The moving force acts at a mechanical disadvantage, but swiftness and range of movement are gained. This is the

form of lever most commonly used in the body. For example, when the forearm is bent up towards the arm, the fulcrum is the elbow joint (Fig. 31); the power is applied at the insertion of the biceps muscle into the radius; the weight is that of the forearm and hand and whatever may be held in the latter, and acts at the centre of gravity of the whole, somewhere on the far side of the point of application of the power. Usually (as in this case) the power-arm is very short, so as to gain speed and extent of movement, the muscles being strong enough to work at a considerable mechanical disadvantage. The limbs are thus also made much more shapely than would be the case were the power applied near or beyond the weight.

Pulleys in the Body.—Fixed pulleys are used in the body; they give rise to no loss or gain of power, but serve to change the direction in which certain muscles pull. One of the muscles of the eyeball, for example, has its origin at the back of the eye socket, from there it passes to the front and ends in a long tendon, before it reaches the eyeball. This tendon passes through a ring attached to the margin of the frontal bone, and then turns back to its insertion on the eyeball. The direction in which the muscle moves the eye is thus quite different from what it would be if the tendon went directly to the eyeball.

Standing.—We slowly learn to stand in the first year after birth, and though we finally come to do it without conscious attention, standing always requires the co-operation of many muscles, guided and controlled by the nervous system. The influence of the latter is shown by the fall following a severe blow on the head, which has fractured no bone and injured no muscle; "the concussion of the brain" stuns the man, and until it has passed off he cannot stand.

When we stand erect, with the arms close by the sides and the feet together, the centre of gravity of the whole adult body lies at the articulation between the sacrum and the last lumbar vertebra, and a vertical line drawn from it will reach the ground between the feet. In any position in which this vertical falls within the space bounded by a line drawn close around both feet, we can stand. When the feet are together the area enclosed by this line is small, and a slight sway of the trunk will throw the centre of gravity of the body outside it; the more one foot is in front of the other, the greater the sway back or forward which will be compatible with safety, and the greater the lateral distance between the feet, the greater the lateral sway which is possible without falling. Consequently, when a man wants to stand very firmly he advances one foot obliquely, so as to increase his base of support in both directions.

In consequence of the flexibility of its joints a dead body cannot be balanced on its feet as a statue can. When we stand, the ankle, knee, and hip joints, if not braced by the muscles, give way, and the head also falls forward on the chest. But (Fig. 43) muscles (1) in front of the ankle joint, and others (I) behind it, by contracting at the same time, keep the joint from yielding; similarly the contraction of muscles (2) in front of the knee and hip joints, with their antagonists (II), make these joints rigid; in like manner, the muscles (III) which run from the pelvis to the back of the head pull against those (3 and 4) which run from the pelvis to the lower end of the breastbone, and from the upper end of the breastbone to the anterior part of the skull, and their balanced contraction keeps the head erect. Since the degree to which each muscle concerned contracts when we stand must be accurately adjusted to the contraction of its antagonist

on the opposite side of the joint, we may easily comprehend why it takes us some time to learn to stand, and why a stunned man, whose muscles have lost guidance from the nervous system, falls.

Locomotion includes all movements of the body in space, dependent on its own unaided muscular efforts, such as walking, running, leaping, and swimming.

Walking.—In walking, the heel of the advanced foot reaches the ground before the toe of the rear foot has been raised from it. In each step the advanced leg supports the body, and the rear foot propels it.

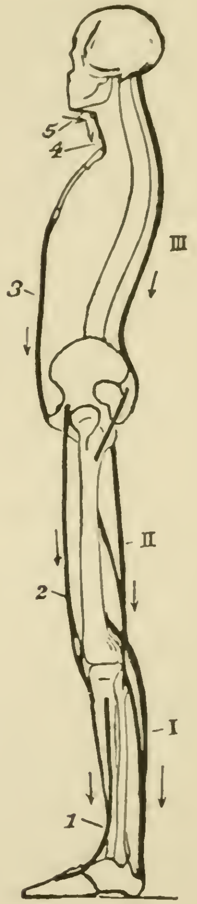

FIG. 43.—Diagram illustrating the muscles (drawn in thick black lines) which pass before and behind the joints, and by their balanced activity keep the joints rigid and the body erect.

A little attention will enable any one to analyze the act of walking for himself. Stand with the heels together and take a step, commencing with the left foot. The whole body is at first inclined forwards, the movement taking place mainly at the ankle joints. This throws the centre of gravity in front of the base formed by the feet, and a fall would result were not the left foot simultaneously raised by bending the knee a little, and swung forwards, the toes just clear of the ground and the sole nearly parallel to it. When the step is completed the left knee is straightened and the foot placed on the ground, the heel touching first; the base is thus extended in the direction of the stride and the fall prevented. Meanwhile the right leg is kept straight but inclined forwards, carrying the trunk

during the step while the left foot is off the ground; the right foot is now raised, commencing with the heel, and when the step of the left leg is completed, only the great toe of the right is in contact with the support. With this toe a push is given which sends the body swinging forward, supported on the left leg, which now in turn is kept rigid except at the ankle joint; the right knee is immediately bent and that leg swings forwards, its foot just clear of the ground, as the left did before. The body meanwhile is supported on the left leg alone. When the right leg completes its step its knee is straightened and the foot thus brought, heel first, on the ground; while it is swinging forwards the left heel is gradually raised, and at the end of the step the great toe alone is on the ground; with this a push is given as was the case with the right foot, and the left leg then swings forward to make the next step. Walking may, in fact, be briefly described as the act of continually falling forward and preventing the completion of the fall by thrusting out a leg to meet the ground in front.

During each step the body sways a little from side to side, as it is alternately borne by the right and left legs. It also sways up and down a little; a man standing with his heels together is taller than when standing with one foot advanced, just as a pair of compasses held erect on its points is higher when its legs are together than when they are apart. In that period of each step when the advancing trunk is balanced vertically over one leg, the walker's trunk is more elevated than when the front foot also is on the ground. Women, accordingly, often find that a dress which clears the ground when they are standing sweeps the pavement when they walk.

The length of each step is primarily dependent on the

length of the legs, though it can be controlled by muscular effort; this control we see in a regiment of soldiers, all of whom have been taught to take the same stride, no matter how their legs vary in length. In natural easy walking, little muscular effort is employed to carry the rear leg forward after it has given its push; it swings on like a pendulum when its foot is clear of the ground. As short pendulums swing faster than long ones the natural step of short-legged people is quicker than that of long-legged.

Running differs from walking in several respects. There is a moment when both feet are off the ground; the toes alone come in contact with it at each step; and the knee joint is not straight at the end of the step. In running, when the rear foot is to leave the ground the knee is suddenly straightened and the ankle joint extended so as to push the toes forcibly on the ground and powerfully impel the whole body forwards and upwards. The knee is then flexed and the foot raised before the toes of the front foot reach the ground. In each step the raised leg is forcibly drawn forward and not allowed to swing passively as in quiet walking. This increases the rate at which the steps follow one another, and the one-legged jump that occurs through the jerk given by the straightening knee of the rear leg, just before it leaves the ground, increases the distance covered at each step.

Hygiene of the Muscles.—The healthy working of the muscles is dependent on a healthy state of the body in general. Hence good food and pure air are necessary for a vigorous muscular system. Muscles also should not be exposed to any considerable continued pressure, since this interferes with the flow of the blood and lymph essential for their nutrition.

Exercise is necessary for the best development of the

muscles. A muscle long left unused diminishes in bulk and degenerates in quality, as is well seen when a muscle is paralyzed and remains permanently inactive because of injury to its nerve; although at first the muscle itself may be perfectly healthy, it alters in a few weeks, and when the nerve is repaired the muscle may be incapable of activity. The same fact is illustrated by the feeble and wasted state of the muscles of a limb which has been kept motionless in splints for a long time; when the splints are removed, it is only after careful and persistent exercise that the long idle muscles regain their former size and power. The great muscles of the "brawny arm" of the blacksmith illustrate the converse fact—the growth of muscles when exercised.

Exercise, to be useful, must be judicious; taken to the point of extreme fatigue, day after day, it may do harm. When a muscle is worked some of its substance is used up; at the same time and afterwards more blood flows to it, and if the exercise is not too violent and the intervals of rest are long enough, the repair and growth will keep pace with or exceed the wasting, but excessive work and too short rest like too little exercise may lead to diminution and enfeeblement of the muscle.

Few persons can profitably attempt to work *hard* daily with both brain and muscle, but all should regularly use both, choosing which to *work* with, and which merely to exercise The best earthly life, that of the healthy mind in the healthy body, can only so be attained. For persons of average physique, engaged in study or business pursuits of a sedentary nature, the minimum of daily exercise should be an amount equivalent to a five or an eight mile walk.

Time for Exercise.—Since extra muscular work means extra muscular waste, and should be accompanied by an

abundant supply of food materials to the muscles, violent exercise should not be taken after a long fast. Neither should it be taken immediately after a meal; a great deal of blood is then needed in the digestive organs to provide materials for digesting the food, and this blood cannot be sent off to the muscles without the risk of an attack of indigestion. Strong and hearty young people may take a long walk before breakfast, but others should wait until after eating before engaging in any kind of hard work.

Varieties of Exercise.—In walking and running the muscles of the lower limbs and trunk are chiefly used, whereas the muscles of the chest and arms are not. Rowing is better, since in it nearly all the muscles are active. No one exercise employs in proper proportion all the muscles, and gymnasia in which different feats of agility are practised so as to call different muscles into action have a deserved popularity. It should be borne in mind, however, that the legs especially need strength, whereas the arms need delicacy of control rather than great strength. Out-of-door exercise in good weather is better than any other, and every one can at least take a walk. The daily "constitutional" is very apt to become wearisome, especially to young persons, and exercise loses half its value if unattended with feelings of mental relaxation and pleasure. Active games, for this reason, have a great value for young and healthy persons; bicycling, golf, lawn-tennis, baseball, and cricket are all attended with pleasurable excitement, and are excellent as exercising many muscles. Such exercises as make one breathe faster and deeper and increase the rapidity and force of the pulse are excellent for giving exercise to the heart and training the respiratory and circulatory nerve centres. The lungs and chest are also developed thereby.

CHAPTER VIII.

WHY WE EAT AND BREATHE.

How is it that the Body can Do Muscular Work?—In the muscles we possess a set of organs capable of moving the body from place to place, of changing the relative positions of its parts, and of lifting external objects; as long as we are alive, some of our muscles are at each moment doing mechanical work. This fact suggests the question, where does this power of working come from?

The Conservation of Energy. — The different natural forces known to us are not nearly so numerous as the chemical elements; we all, however, know several of them, as light, heat, electricity, and mechanical work. One of the greatest discoveries of the nineteenth century is that these different natural forces, or *forms of energy*, can be turned one into another, directly or indirectly. Kinds of energy are transmutable, while, so far as we know at present, kinds of matter are not. We cannot, as the alchemists hoped, turn iron or mercury into gold, but we can turn heat into light, into electrical force, or into mechanical work. When such transformations are made it is always found that a definite amount of one kind of energy disappears to give rise to a definite amount of another. In other words, it has been discovered that energy cannot be created. If we take a given quantity of heat we can turn it into mechanical work; if we then

turn all this mechanical work back into heat we get again exactly the quantity of heat which disappeared when the mechanical work appeared, and so with all other transformations of energy from one kind to another and back again. This fact that *energy or work-power can be turned from one kind into another, and often back again, but never created from nothing or finally destroyed*, is known as *the law of the conservation of energy*.

Illustrations of the Conservation of Energy.—In a steam-engine, heat, which is the best known kind of energy, is produced in the furnace. When the engine is at work all of this energy does not leave it as heat; some is turned into mechanical work, and the more work the engine does the greater is the difference between the heat generated in the furnace and that leaving the machine. If, however, we use the work to rub two rough surfaces together we can get the heat back, and if (which of course is impossible in practice) * we could avoid all friction between the moving parts of the machine, and have all parts of the engine at the end of the experiment at exactly the same temperature as at the beginning, the quantity of heat obtained plus the quantity which has been carried off from it by the air since its fires were lighted would be exactly equal to the amount of heat originally generated in the furnace of the engine. Having turned some of the heat into mechanical work we could thus turn the work back into heat again, and find it yield exactly the amount which seemed lost.

Or we might use the engine to drive an electro-magnetic machine and so turn part of the heat liberated in its furnace,

* The losses of heat through radiation and the heating of the air, and the losses of mechanical energy by friction between the parts of machines, are great and constantly diminish the supply of force.

first into mechanical work, and this afterwards into electricity; and if we choose to use the latter with the proper apparatus, as now used for electric lighting, we can turn more or less of it into light, and so have a great part of the energy which first became conspicuous as heat in the engine furnace, now manifested in the form of light at some distant point. In theory, starting with a given quantity of one kind of energy, we may turn it into one or more other forms; but if we collect all the final forms and retransform them into the first, we shall have exactly the amount of it which disappeared when the other kinds appeared.

Why We Need Food.—Energy, as we have seen, cannot be created from nothing; since the body constantly expends energy, it must have a steady supply. This supply comes from the energy liberated when substances in the body are burned, or, as the chemists say, *oxidized*, just as that used by a locomotive comes from the burning or *oxidation* of coal or wood in its furnace. In consequence of this constant oxidation, new materials must constantly be supplied to make up for those used for oxidation. These new materials are provided in our *food*. One chief reason for eating is that we may replace the material which has been burned to set free the energy needed for our muscular efforts.

Why the Body is Warm.—Keeping warm is a very important matter, for experiment shows that no tissue of the human body works well when cooled down even a few degrees below 98.5° F., its natural healthy temperature. Careful experiments prove that when a muscle works it becomes hotter, and we all know that exercise makes us warm. This shows that the oxidation which takes place in a working muscle is not all turned into mechanical work, but a good share of it appears as heat. What is true of muscle is true of

all other organs of the body when they work. No matter what their kind of work, material is oxidized, and some of the energy set free by the oxidation appears as heat, assisting to keep the body warm and at its best working temperature.

A Second Reason Why We Need Food.—Since the body works best at a temperature higher than that of the surrounding air (except on a very hot day), and in health always keeps at this temperature, it must lose heat nearly all the time. At night each of us is, in health, just as warm as in the morning, and in the morning as when we went to bed, though we have lost heat to the air during the day, and to the bedclothes at night. In order to keep our bodies at the temperature most suitable to their activity, they must, therefore, generate heat all the time, to compensate for its continued loss. In this necessity of generating heat we find a second reason for taking food.

The Influence of Starvation upon Muscular Work and Animal Heat.—The body does not live, work, and keep warm by means of any peculiar vital force or energy which inhabits it, but by utilizing the energy set free in it by the oxidation of foods, or of substances made in it from foods. When a man is deprived of food, the supply of material for oxidation is cut off; the body first uses up any reserve of nutritious matter which may have been stored up in it when the starvation commenced, then the tissues are attacked, and as they are burned up the body becomes weaker and weaker until death supervenes.*

* When warm-blooded animals are starved their temperature slowly falls; and when it comes down to about 77° F. (25° C.) death occurs. The various tissues at that temperature can no longer work so as to maintain life.

How long a man totally deprived of food can keep alive depends partly on how much reserve material, capable of oxidation, he has stored up in him when the starvation period commences; but largely, also, on the extent to which he can avoid muscular work and loss of heat. The breathing movements and beat of the heart must go on, but if the individual lies quiet in bed he need do little or no other muscular work; and if he is well covered up with blankets, the loss of heat from the body is slight and calls for but little oxidation of the tissues to compensate for it.* Also, a healthy fat person will survive starvation longer than a healthy lean one; during the process his fat is slowly burnt; but so long as it lasts he can supply his muscles with something which can be oxidized to yield working power and maintain his temperature. Fat is, in fact, a sort of reserve fuel, laid up in the body, and one can hardly be said to begin to *starve* until his fat has nearly all been used up.†

Oxidations in the Body.—In the preceding paragraphs oxidation and burning have been used as equivalent phrases, in accordance with the teachings of chemistry. To the chemist a substance is *burned* when it is combined with

* Hence Dr. Tanner and "fasting girls" keep in bed, warmly covered up, most of the time. The losses of the body in mechanical work and heat are thus reduced to a minimum, and consequently the oxidation of the food reserves stored in the body at the beginning of the fast.

† Some warm-blooded animals, as bears, *hibernate*, that is, sleep all through the winter and take no food. They feed well in the warm weather, and are quite fat at the close of autumn, when they seek some sheltered place to winter in. This shelter and their warm, furry coats make the loss of heat very little; the animal, except for its breathing and the beat of its heart, hardly ever moves during the winter, and even those necessary movements are reduced to the fewest possible, the breathing and heart beat being much slower than during the summer. With return of warm weather the creature wakes up again, but is then lean and weak, having burnt up its fat and part of its muscle during its winter sleep.

oxygen, whether this combination takes place slowly or rapidly. If the combination occurs rapidly, the burning or *oxidizing* mass becomes very hot and also gives off light. Such a rapid and vigorous oxidation is called a *combustion;* no combustions take place in our bodies.

It has, however, been proved that whether the combination of oxygen with an *oxidizable*, or *burnable*, substance takes place rapidly or slowly, at the end of the process exactly the same amount of energy will have been set free in each case. When the oxidation occurs in a few seconds, the oxidizing mass becomes very hot; when it occurs slowly, in a few days or weeks, the mass will never be very hot, because the heat set free in the process is carried off nearly as fast as it appears.

Illustrations of Oxidations at a Low Temperature.—If a piece of magnesium wire be ignited in the air, it will become white-hot, flame, and leave at the end of a few seconds only a certain amount of incombustible *rust* or *magnesia*, which consists of the metal combined with oxygen; under these circumstances it has been burnt or *oxidized* quickly at a high temperature. The heat and light evolved in the process represent the energy which is set free by the union of the metal and oxygen. We can, however, oxidize the metal in a different way. If, for instance, we leave it in damp air, it will be gradually turned into magnesia without having ever been hot to the touch or luminous to the eye. The process then, however, takes days or weeks, but in this slow oxidation just as much energy is liberated as in the former case, although now all takes the form of heat. The slowly oxidizing magnesium is, in consequence, at no moment noticeably hot, since it loses its heat to surrounding objects as fast as it generates it. The oxidations occurring in our bodies are of this slow kind.

An ounce of arrowroot oxidized in a fire liberates exactly as much energy as if burned in the body, but the oxidation takes place in a shorter time and at a much higher temperature.

Oxidation in the Presence of Moisture.—Wet wood or wet coal we know will not burn easily, but other kinds of oxidation which take place in the presence of moisture are well known. The rusting of iron, for example, is an oxidation of the metal, and takes place faster in damp air than in dry; during the slow rusting in moisture just as much heat is set free as if the same compound of iron and oxygen were prepared in a more rapid way. Such experiments throw great light on the oxidations which take place in our own bodies. All of them are slow oxidations, which never at any one moment give off a great amount of heat, and all occur in the wet tissues.

Summary:

(1) The body is enabled constantly to expend energy in muscular work and in heat only because the law of the conservation of energy is operative here as elsewhere in nature's dominions.

(2) This law is: Energy can be transformed from one kind to another, but can never be created from nothing, increased, diminished, nor finally destroyed.

(3) In accordance with this law the energy expended by the body must have a source.

(4) Investigations have shown that the source of the body's energy is found in the oxidation of materials.

(5) Such oxidizable materials are furnished by food, which includes not only that taken into the body at any time, but storage substance, such as fat.

(6) Rapid and vigorous oxidation is combustion.

(7) The same amount of energy is liberated whether the oxidation is slow or rapid.

(8) In the body oxidation is always relatively slow, and takes place in the presence of moisture.

(9) Hence, by the transformation of energy through oxidation in the body of the materials furnished by food, the body is enabled to expend *(a)* muscular energy, whereby its work is accomplished; and *(b)* heat, whereby its tissues are kept at their best working temperature and the constant outgo of heat compensated.

The Oxygen Food of the Body.—Hitherto we have considered the energy supply of the body only from one side; we have regarded it as dependent on the constant supply of oxidizable material. But this is only half the question, since if substances are to be oxidized there must be a provision of oxygen to oxidize them.

In order that a steam-engine may work and keep warm it is not merely necessary that it have plenty of coal, but it must also have a draught of air through its furnace. Chemistry teaches us that the burning in this case consists in the combination of a gas called oxygen, taken from the air, with carbon and hydrogen in the coals; when this combination takes place a great deal of heat is given off. The same thing is true of our bodies. In order that food matters may be burnt in them and enable us to work and keep warm, they must be supplied with oxygen; this they get from the air by breathing. We all know that if the supply of air be cut off, a man will die in a few minutes; his food is no use to him unless he gets oxygen. While he usually has stored up in his body an excess of food matters, he has little or no reserve of oxygen. In ordinary language we do not call oxygen a food, but restrict that name to the solids and liquids which we swallow; but

inasmuch as it is a material which we must take from the external universe into our bodies to keep us alive, oxygen is really a food. *Suffocation*, as death from deficient air supply is named, is really death from oxygen starvation.

CHAPTER IX.

NUTRITION.

The Wastes of the Body.—A man takes into his body daily several pounds of foods of various kinds, as meats, bread, vegetables, and water, yet he grows no heavier. It is, therefore, clear that his body must in every twenty-four hours return, on the average, to the outside world about as great a weight of matter as it receives from it. Even in childhood, while growth is taking place and the body becoming heavier, the gain is always much less than the weight of the foods swallowed. The materials given off daily from the body, which balance more or less accurately the receipts from the outside world, are its *wastes*, and are chiefly things which cannot be burned. Much of the food taken in can be, and is, oxidized to enable us to move and keep warm. When burned it is of no further use to us, and would only clog up the various organs, as the ashes and smoke of an engine would soon put out its fire if they were allowed to accumulate in the furnace. The chief wastes * of the body are *carbon dioxide gas*, *water*, and a substance related to ammonia called *urea*.

* Chemically these wastes are :

Carbon dioxide	$= CO_2$
Water	$= H_2O$
Urea	$= CON_2H_4$.

Receptive and Excretory Organs.—Those organs of the body whose function it is to gather new material from outside for its use are known as *receptive organs*. There are two chief sets of these—one to receive oxidizable things, and the other to receive oxygen. The first set is represented by the alimentary canal, consisting of *mouth*, *gullet*,* *stomach*, and *intestines*. It takes in food and drink. The second set consists of the lungs, with the air passages leading to them. Their business, as receptive organs, is to absorb oxygen.

The organs whose duty it is to get rid of waste materials formed in the body are called *excretory organs*. The three most important excretory organs are the *lungs*, the *kidneys*, and the *skin*. The lungs give out carbon dioxide gas and water; the kidneys get rid of urea and water; and the skin, of water, common salt and a minute quantity of urea.

The Intermediate Steps between Reception and Excretion.—Between the taking of oxidizable substances into our mouths and oxygen into our lungs, and the return of oxidized matters from our bodies to the surrounding world, a great many intermediate steps take place. The alimentary canal (see Fig. 1) is a tube which runs through the body but nowhere opens into it. So long as food lies in this tube it therefore does not really form a part of the body, and is of no use to it; it resembles coals in the tender of a locomotive, waiting to be transferred to the furnace In our bodies the furnace is everywhere; wherever there is living tissue, substances are burned to enable it to work. Hence the food or fuel must-be brought to every corner of our frames.

Digestion.—A great part of our food is solid, and could not of itself get outside of the alimentary canal. To render

* The technical name for the gullet is *œsophagus*.

it available it must be dissolved so that it can soak through the walls of the stomach and intestines. For this purpose we find a set of *digestive organs* to make solvent juices and pour them upon the food which we swallow, and so get it into a liquid state in which it can be absorbed.

Circulation.—If the solution containing our digested food simply soaked through the walls of the alimentary canal, it could not reach the distant parts, as the brain or the muscles of the limbs. We find, therefore, in the body a set of tubes containing blood, called blood vessels; the blood is driven through these by a pump, *the heart.* Much of the dissolved food passes into the blood vessels of the alimentary canal, and from them is carried by connecting blood vessels to every organ, no matter how remote. As the blood flows unceasingly, round and round in its vessels, from part to part, the organs concerned in moving and conveying it are called *circulatory organs*, and the blood flow itself is known as *the circulation.*

Absorbents.—Some of the dissolved food is taken up into another set of tubes in the walls of the alimentary canal; these tubes carry it afterwards into the blood vessels. They are called the absorbents, or *lymphatics.*

Respiration.—The blood in its course flows through the lungs. It is necessary not merely that food but oxygen also should be carried to every part of the body. As the blood traverses the lungs it picks up oxygen from the air in them; this air is then replaced by taking a fresh breath, and so on. The organs thus concerned are the *respiratory organs*, and the act of renewal is *respiration.*

Assimilation.—As each organ works it oxidizes; some of its substance is broken down by combination with oxygen brought to it by the blood, and is thus converted into burnt

waste matter. The blood, as we have seen, brings, however, not merely oxygen but also food matters in solution. These ooze through the walls of the blood vessels, and are taken up by the living tissues and built into new tissues like themselves, to replace the part which has been used up and destroyed. This building and repair of tissues and organs from the dissolved food obtained from the blood is known as *assimilation*—in plain English, "a making alike." Each living tissue takes from the blood foods which are not like itself, and builds them up into a form of matter like its own. The converse process, which accompanies all vital action, the breaking down into wastes of a living tissue when it works, is called *dissimilation*, or "a making unlike."

The Relation of the Circulatory Organs and the Absorbents to Excretion.—It is essential to the body that its wastes be carried off. Here again the blood vessels and absorbents, or lymphatics, come into play. Lymphatics are found not only in the walls of the alimentary canal, but all over the body. The wastes of each working tissue are passed out into them, and by them carried into the blood vessels; these in turn carry the wastes to the lungs, kidneys, and skin which get rid of them. The blood is thus as important for removing the waste matters of an organ as for supplying it with food and oxygen.

Nutrition.—From what has been said above, it is clear that the nourishment of the body is a very complicated process. It implies—(1) the reception of food from outside; (2) the digestion of food; (3) the absorption of digested food; (4) the absorption of oxygen in the lungs, and its conveyance by the blood to every organ; (5) the conveyance of absorbed food and oxygen to all parts by the blood; (6) assimilation or the building up of new tissue from materials

brought by the blood; (7) disassimilation, or the breaking down of working tissues by combination with oxygen; (8) the taking up of wastes from the different organs; and (9) the conveyance of these wastes by the blood to excretory organs which pass them out of the body.

In subsequent chapters we shall have to consider in more detail Digestion, Circulation, Absorption, Respiration, and Excretion. The sum total of the actions of all the organs concerned in the nourishment of the body is known as the function of *nutrition*. As will be explained later, some of the food fulfils other purposes than the formation of energy yielding material.

CHAPTER X.

FOODS.

Foods as Tissue Formers.—In the last chapter we have considered foods merely as sources of energy, but they are also required to build up the substance of the body. From birth to manhood we increase in bulk and weight not merely by accumulating water and such substances, but by forming more bone, more muscle, more brain, and so on, from the things which we eat. Even after full growth, when the body ceases to gain weight, there are probably some constructive processes going on as the tissues are broken down and reconstructed.

Foods are therefore needed not only to supply the body with work-power by their oxidation, but to supply material from which tissue can be reconstructed.

What Foods must Contain.—Most foods serve both for energy supply* and tissue formation; they are probably built up by the living cells into new forms before they are oxidized

* Whether any food is ever oxidized in the body before being built up into a tissue, as coal is burnt in an engine without ever forming part of the engine, must still be regarded as an open question in physiology. The old doctrine that some foods, as starch and sugar, were useful only to set free heat, and others, as albumen and flesh, alone built tissue, must be given up. It seems certain that under some conditions sugar and starch may be used in building tissue, though they cannot do it alone; but whether they are under any circumstances ever burnt before making part of a tissue is not certain. On the other hand, there is reason to suspect that albuminous substances may be oxidized in the body without ever forming part of a living cell.

to set the energy free. The living tissues when analyzed are found to consist mainly of carbon, hydrogen, nitrogen, and oxygen, and we might at first suppose that these chemical elements in their uncombined form would serve to nourish us. Experience, however, teaches that this is not the case. Four fifths of the air is nitrogen, but we cannot feed on it; hydrogen gas is of no use as a food; and a lump of charcoal (carbon) might fill the stomach, but would not keep a man from starving. Oxygen can be utilized when taken by the lungs from the air; but all other elements to be of use as food must be taken, not in their separate state, but in the form of complex compounds, in which they are chemically combined with other things; as, for example, in starch, sugar, fat, oil, and albuminous substances.

The Special Importance of Albuminous or Proteid Foods.—All the active tissues of the body are found to yield on chemical analysis large quantities of proteids. (See p. 15.) So far as we know at present the human body (like that of most animals) is unable to make proteids out of other things. Given one variety of them it can turn it into other varieties, but it cannot make proteids from things which are not proteids. Hence these albuminous or proteid substances are an essential article of diet.

The Limited Constructive Power of the Animal Body.—From what has been said above, it is clear that our bodies are, on the whole, destructive rather than constructive in relation to the outer world. They require for their nutrition very complex chemical compounds (starch, sugar, fat, proteids),* build these up into living tissues, or oxidizable forms,

* Starch.......................... $C_6H_{10}O_5$
Sugar.......................... $C_6H_{12}O_6$
Fat (variable).................... $C_{51}H_{104}O_9$
Proteid (variable)................ $C_{72}H_{112}N_{18}O_{22}S$

then oxidize them and return the carbon, hydrogen, and nitrogen to the outer world in much simpler chemical compounds (carbon dioxide, water, and urea). None of these latter substances is capable of nourishing an animal; it cannot use them to build up its tissues or set energy free.

How Plants Supply Food for Animals, and Animals Food for Plants.—Since animals cannot utilize the simple substances furnished by nature as food, but must consume complex substances, as proteids, fat, and sugar, the question naturally suggests itself, How is it that the supply of these is kept up? For example, the supply of proteids, which cannot be made artificially by any process known to us. The answer is, that animals live on the things which plants make, and plants live on the carbon dioxide, water, and ammonia (urea) which animals excrete.

As regards our own bodies the question might, indeed, be apparently answered by saying that we get our proteids from the flesh of the other animals which we eat. But then we have to account for the possession of proteids by those animals, since they cannot make them from urea, carbon dioxide, and water any more than we can. The animals whose flesh is used by us as food get their proteids from plants, which are the great proteid formers of the world. The most carnivorous animal really depends for its essential food upon the vegetable kingdom; the fox that devours a hare lives on the proteids of the plants which the hare had previously eaten and built into his own tissues.

Non-oxidizable Foods.—Besides our oxidizable foods a large number of necessary food materials are not oxidizable, or at least are not oxidized in the body. Typical instances are afforded by water and common salt. The use of these is in great part physical: the water, for instance, dissolves ma-

terials in the alimentary canal, and carries the solutions through its walls into the blood and lymph vessels, so that they can be conveyed from place to place; and it permits interchanges by enabling the things it has dissolved to soak through the walls of the vessels. The salines also influence the solubility and chemical interchanges of other things present with them. *Fibrinogen*, one of the proteids which is carried in the blood all over the body to supply albuminous material to the tissues, is, for example, insoluble in pure water, but dissolves readily if a small quantity of common salt is present. Beside such uses, the non-oxidizable foods have probably other functions: for example, the lime salts give their hardness to the bones and teeth. The body is a self-building and self-repairing machine, and the material for this building and repair, as well as the fuel or oxidizable foods which yield the energy the machine expends, must be supplied in the food. While experience shows us that even for machinery construction oxidizable matters are largely needed, it is nevertheless a gain to replace such substances by non-oxidizable material when possible; just as, if practicable, it would be advantageous to construct an engine out of a substance which would not rust, although other conditions determine the selection of iron for building the greater part of it.

General onsiderations.—Foods to replace matters which have been oxidized must be themselves oxidizable; they are *force generators*, but may be and generally are also tissue formers. They are nearly always complex organic substances derived from other animals or from plants. Foods to replace matters not oxidized in the body, as water and salt, are *force regulators*, and are for the most part fairly simple inorganic compounds. Among the force regulators

we must, however, include certain foods, which, although oxidized in the body and serving as sources of energy, yet produce effects greatly out of proportion to the amount of energy which they thus set free. Their influence as stimulants in exciting certain tissues to activity, or as agents checking the activity of parts, is more marked than their direct action as force generators, and they may be classed as *accessory foods*. As examples we may take condiments: mustard and pepper are not of much use as sources of energy, although they no doubt yield some when oxidized; we take them for their stimulating effect on the mouth and other parts of the alimentary canal, by which they promote a greater flow of the digestive secretions or an increased appetite for food. *Thein*, again, the active principle of tea and coffee, is taken for its stimulating effect on the nervous system rather than for the amount of energy which is yielded by its own oxidation.

To the above consideration of foods should be added the condition that *neither the substance itself nor any of the products of its chemical transformation in the body shall be injurious to the structure or action of any organ; otherwise it is a poison, not a food.**

Alimentary Principles.—The substances which we call foods are usually mixtures of several *foodstuffs* with substances which are not foods at all. Bread, for example, contains water, salts, gluten (a proteid), some fats, much starch, and a little sugar; all these are true foodstuffs, but mixed with them is a quantity of *cellulose* (the chief chemical constituent of the walls which surround vegetable cells), which

* This, of course, is true only when the substances are taken in the ordinary moderate or physiological amounts. Many substances become harmful or poisonous if taken in excess, e.g. oxygen, salt, meat, etc.

is not a food, since it is incapable of digestion and absorption from the alimentary canal. Chemical examination of all the common articles of diet shows that the actual number of important *foodstuffs* is small; they are repeated in various proportions in the different foods we eat, mixed with small quantities of different flavoring substances, and so give us a pleasing variety in our meals; but the essential substances are much the same in the fare of the artisan and in the "delicacies of the season." The chief foodstuffs, which are found repeated in many different foods, are known as "*alimentary principles*," and the nutritive value of any article of diet depends on the amount of these foodstuffs present, far more than on the various agreeable flavoring matters which cause certain things to be sought after and to have a high market value. Alimentary principles may be conveniently classified into proteids, fats, carbohydrates, and inorganic bodies.

Proteid Alimentary Principles.—Of the nitrogenous foodstuffs the most important are proteids: they form an essential part of all diets, and are obtained both from animals and plants. The most common and abundant are myosin and syntonin, found in the lean of all meats, egg albumin, casein of milk and cheese, gluten and vegetable casein from various plants.

Beside these proteid substances, all of which are apparently able to act as tissue builders, there is a class of nitrogenous substances which do not possess this power though they are oxidized in the body to yield energy. This class is represented by gelatin, derived from connective tissue and bones, and by chondrin, from cartilage. As force producers they have considerable value, but are not nearly as important food for invalids as was at one time supposed.

Necessity of Proteid Food.—Experiments have shown that the excretion of nitrogen (chiefly as urea) in a well-fed animal is equal to the amount of nitrogen taken in with the food.* This balance of income and expenditure is called *nitrogenous equilibrium*. If the nitrogen of the food is reduced below a certain amount, more nitrogen is excreted than is replaced by the food. This excess of expenditure comes from the fleshy tissues of the animal, which are thus wasted away. All animals thus become flesh-eating (carnivorous) when starving.

Fats and Oils.—The most important of these are stearin, palmatin, margarin, and olein, which exist in various proportions in animal fats and vegetable oils, and butter, which contains a peculiar fat known as butyrin. All fats are compounds of glycerin with fatty acids, and, speaking generally, are useful as food if fusible at the temperature of the body. The stearin of beef and mutton fats is not by itself fusible at the body temperature, but as eaten it is mixed with so much olein as to be melted in the alimentary canal.

Artificial butters, such as margarin, oleomargarin, butterine, and cocoa butter, are made of the more easily melted animal or vegetable fats flavored to resemble butter by being churned in butter milk. They are easily digested and possess practically the same nutritive value as butter.

Fats and oils are rich in carbon and hydrogen, but contain little oxygen. Hence their oxidation liberates much energy.

$$\overset{\text{Fat.}}{C_{51}H_{98}O_6} + \overset{\text{Oxygen.}}{145O} = \overset{\text{Carbon dioxide.}}{51CO_2} + \overset{\text{Water.}}{49H_2O}.$$

Carbohydrates.—These are mainly of vegetable origin. The most important are *starch* (found in nearly all vegetable

* While an animal is growing, the excretion of nitrogen is slightly less than the income owing to its storage in the growing flesh.

foods), *dextrin*, *gums*, *grape sugar* (found in most fruits), and *cane sugar*. *Sugar of milk* and *glycogen* (animal starch from the liver) are alimentary principles of this group derived from animals. All carbohydrates, like the fats, consist of carbon, hydrogen, and oxygen, but the percentage of oxygen in them is much higher than in fats. In fact oxygen is present in just the right proportion to satisfy all the hydrogen; hence only carbon remains to be oxidized. They have therefore less power of combining with additional oxygen than fats and so are not capable of yielding as much energy to the body.

$$\underset{\text{Sugar.}}{C_6H_{12}O_6} + \underset{\text{Oxygen.}}{12O} = \underset{\text{Carbon dioxide.}}{6CO_2} + \underset{\text{Water.}}{6H_2O}.$$

Fuel Values of Food Principles.—The heat produced by the combustion of weighed quantities of food materials has been determined by numerous experimenters, and the average of the results is expressed in the following table:

	Calories.	Foot-tons.
1 gram of proteid (dry)	4.1	6.3
1 " " fats	9.3	14.2
1 " " carbohydrates (dry)	4.1	6.3

Experiments have further shown that the energy produced in the body (heat, muscular work, etc.) by the oxidation of the food substances is practically equivalent to that obtained by combustion.*

* The heat units used by physiologists represent the amount of heat necessary to raise the respective amounts of water one degree Centigrade.

1. kilo	water 1° C. = *Calorie*	= 1.0	pound water	4° F.
1. gram	" 1° C. = *calorie*	= 0.001	" "	4° F.
0.001 gram	" 1° C. = *micro-calorie*	= 0.000001	" "	4° F.

One Calorie is equivalent in mechanical energy to 1.53 foot-tons.
One calorie " " " " " " 0.00153 "

Inorganic Foods.—The most important of these are water, common salt, and the chlorides, the phosphates and the sulphates of potassium, magnesium, and calcium. A sufficient quantity of most of these substances, or of the material for their formation, exists in all ordinary articles of diet, so that we do not take them in a separate form. Water and table salt form exceptions to the rule that inorganic bodies are eaten imperceptibly along with other things, since the body requires more of each daily than is usually supplied in that way. It has been maintained that salt as a separate article of diet is an unnecessary luxury, and there seems to be some evidence that certain savage tribes live without more than they get in the meat and vegetables which they eat. Such tribes are, however, said to suffer from intestinal parasites; and there is no doubt that to many animals as well as most men the absence of salt from their diet is a terrible deprivation. Buffaloes and other creatures are well known to travel miles to reach "saltlicks"; of two sets of oxen, one allowed free access to salt, and the other given none save what existed in its ordinary food, it was found after a few weeks that those given salt were in much better condition. In man the desire for salt is so great that in regions where it is scarce it is used as money. In some parts of Africa a small quantity of salt will buy a slave, and to say that a man commonly uses salt at his meals is equivalent to stating that he is a millionaire. In British India, where the poorer natives regard so few things as necessaries of life that it is hard to levy any excise tax, a large part of the revenue is derived from a tax on salt, which even the poorest will buy. In the Austrian Empire it has been found that youths who have fled to the mountains and there led a wild life to avoid military conscription, will come

down to the villages to purchase salt, at the risk of liberty and even of life.

The Nutritive Value of Different Foods.—All *meats*, whether derived from beast, bird, or fish, are highly valuable foods. They contain abundant albumen, more or less fat, and when cooked, their connective tissue is in great part made soluble by being turned into gelatine. *Pork* is the least easily digested form of fresh meat, since it contains a larger percentage of fat than most. This fat, which, by its oxidation liberates much heat, makes it a good food in cold weather for persons with a good digestion. Pigs are, however, especially liable to a dangerous parasite, called *trichina*, which lives in their muscles, and may be transferred to man if the pork is not thoroughly cooked. *Salted meats* of all kinds are less digestible and less nutritious than fresh. *Milk* contains an albuminous substance (casein), also fats (butter), and sugar, known as *sugar of milk*, in addition to useful mineral salts. It will support life longer than any other single food. *Cheese* consists essentially of the casein of milk, and is a very nutritive albuminous food. *Eggs* contain albumens and fats of high nutritive value, but they are not as easily digested when cooked too long. *Wheat* contains more than a tenth of its weight of proteids, more than half its weight of starch, some sugar, and a little fat. The proteid of wheat flour is mainly *gluten*, which when moistened with water forms a tenacious mass, and gives to wheat bread its superiority. When the dough is made, yeast is added to it and causes fermentation by which some of the starch is changed into sugar, then into alcohol and carbon dioxide. If the fermentation is allowed to go too far, the alcohol is changed into acetic and other acids, and sour bread results. The carbon dioxide

imprisoned in the tenacious dough and expanded by heat during baking, forms cavities in it, and causes the dough to "rise" and make "light bread," which is not only more pleasant to eat but more easily digested than heavy. Some grains contain a larger percentage of starch, but less gluten, than wheat; when bread is made from them the carbon dioxide gas escapes so readily from the less tenacious dough that it does not expand the mass properly. *Corn* contains less proteid, more starch, and more fat than wheat and is very nutritious. *Rice* is poor in proteids, but very rich in starch. *Peas* and *beans* are rich in proteids and contain about half their weight of starch. *Potatoes* contain a great deal of water and only about two parts of proteids and twenty of starch in a hundred parts by weight, but are rich in useful salts. Other *fresh vegetables*, as carrots, turnips, and cabbages, as well as *fruits*, are valuable mainly for the salts they contain; their weight is chiefly due to water, and they contain but little starch, proteids, or fats. Some kind of fresh vegetable is, however, a necessary article of diet, as shown by the scurvy * which used to prevail among sailors before fresh vegetables or lime-juice were supplied to them.

Alcohol as a Food.—Evidence goes to show that alcohol in moderate doses is oxidized in the body and yields energy, but cannot build up or restore exhausted tissue. In certain diseases the fact that it requires no digestion and is rapidly absorbed gives it considerable value. The amount of alcohol which can be taken for food, however, is so slight because of its marked stimulating effect that under normal conditions it is practically valueless for food purposes. Its frequent use

* Scurvy is characterized by swelling and bleeding of the gums, loosening of the teeth, and great weakness ending in death. It was especially frequent among whalers.

may undoubtedly lead to a serious diminution of vitality, lessened resistance to disease, diminished endurance of fatigue, heat, and cold, and to pathological conditions of the vital organs, such as an overgrowth of connective tissue and fat. The consumption of alcohol has so frequently led to wasted opportunities, suffering, and even crime that it is the part of wisdom to avoid its use.

Tea and Coffee are to be regarded as stimulants rather than foods. The amount of nourishment in a cup of either is but little. Both have, however, some influence in removing the sense of fatigue, and when occasionally taken in moderate doses leave as a rule no injurious after-effects. For relieving fatigue, tea and coffee are superior to alcohol, but neither should be used as a substitute for rest and sleep; in fact it may be questioned whether the habitual use of either is advisable. Sportsmen out for a long day's shooting find cold tea superior to spirits; military commanders find a ration of coffee far better than one of whiskey for fatigued troops, and all arctic explorers have come to a similar conclusion.

Cooking.—When meat is cooked most of its connective tissue is turned into gelatin, and the whole mass becomes softer and more readily broken up by the teeth. In boiling meat it is a good plan to put it first into boiling water in order to coagulate the albumen at the surface and thus form a dense coat which keeps flavoring matters and salts from passing into the water. After the first few minutes the cooking should be continued at a lower temperature; meat boiled too fast is hard, tough, and stringy. In roasting or baking meat, it is also advisable to put it close to the fire or in a hot oven for a short time, and then to complete the cooking more slowly.

The cooking of vegetable foods is of considerable impor-

tance. Starch is the chief nutrient matter in most of them, and raw starch is much less easily digested than cooked since it is enclosed in a thick cell wall of indigestible cellulose which is broken down by cooking. When starch is heated it is turned into a substance known as *soluble starch*, which is easily dissolved by the digestive liquids; there is therefore a scientific foundation for the common belief that the crust of

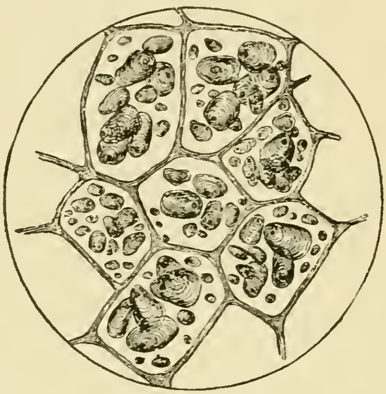

FIG. 44.—Cells of a raw potato, with starch grains in natural condition.

a loaf is more digestible than the inside, and toast than fresh bread.

The Oxidizable Matters Required Daily by the Body.—The amount of food required daily depends upon the quantity of material used up by the body in each twenty-four hours; this varies both in kind and amount with the work done and the organs most used. In children a certain excess is required to furnish material for growth. It is impossible to state accurately beforehand just what any individual will require, but a general idea may be arrived at by taking the average daily losses, by excretion, as determined by many experiments made on different persons. Such experiments show that a man of average size and doing ordinary work needs rather more than 274 grams ($9\frac{1}{2}$ ounces) of carbon to

replace his loss of that element, and about 20 grams of nitrogen ($\frac{7}{10}$ of an ounce). Some hydrogen is also required, as the body daily excretes more water than it receives through food and drink ; this extra amount implies a loss of hydrogen, which has combined with oxygen in the body to form water.

The Advantages of a Mixed Diet.—Since proteid foods contain carbon, nitrogen, and hydrogen, life may be maintained on them if the necessary salts, water, and oxygen be also supplied; but such a diet would not be economical. Ordinary proteids contain in 100 parts about 52 of carbon and 15 of nitrogen, so a man fed on them alone would get about $3\frac{1}{2}$ parts of carbon for every 1 of nitrogen. His daily losses are not in this ratio, but about 15 parts of carbon to 1 of nitrogen : therefore to get enough carbon from proteids far more than the necessary amount of nitrogen must be taken. Of dry proteids 527 grams (1 pound $2\frac{1}{2}$ ounces) would yield the necessary carbon, but would contain 79 grams ($2\frac{3}{4}$ ounces) of nitrogen, or four times more than is necessary to cover the daily losses of that element from the body. Fed on a purely proteid diet a man would, therefore, have to digest a vast quantity to get enough carbon, and in eating and absorbing it, and in getting rid of the excess nitrogen (which is useless to him), a great deal of unnecessary labor would be thrust upon the digestive and excretory organs. Were a man to live on bread alone, he would also force much unnecessary work on his organs. Bread contains little nitrogen in proportion to its carbon, and to get enough nitrogen far more carbon than could be utilized would have to be eaten, digested, and excreted daily.

The human race has discovered this fact : men use, where they have a choice, richly proteid substances to supply the

nitrogen needed, but derive the carbon mainly from non-nitrogenous foods of the fatty carbohydrate kinds, and so avoid excess of either nitrogen or carbon. For instance, lean beef contains about 25 per cent of dry proteid, and this in turn contains 15 per cent of nitrogen. Consequently 542 grams (1 pound 3 ounces) of lean meat would supply the nitrogen needed to compensate for a day's losses. But the proteid contains 52 per cent of carbon, so the amount of carbon in the above weight of fatless meat would be 69 grams (or nearly $2\frac{1}{2}$ ounces), leaving 205 grams (or rather more than 7 ounces) to be got either from fats or carbohydrates. The necessary amount is contained in 256 grams (or about 9 ounces) of ordinary fats, or in 460 grams (a little over a pound) of starch; hence either of these with the above quantity of lean meat would form a far better diet both for the system and the purse than meat alone.

As already pointed out, nearly all common foods contain several *foodstuffs*. Good butcher's meat, for example, contains nearly half its dry weight of fat, and bread in addition to proteids contains starch, fats, and sugar. In neither of them, however, are the foodstuffs mixed in the physiologically best proportions, and the custom of consuming several of them at each meal, or different ones at different meals during the day, is not only agreeable to the palate but in a high degree advantageous to the body. The strict vegetarians who do not eat even such substances as eggs, cheese, and milk, but confine themselves to a purely vegetable diet, which is always poor in proteids, take daily far more carbon than they require, and are to be congratulated on their excellent digestions which are able to stand the strain. Those so-called vegetarians who use eggs, cheese, and other animal substances can of course get on very well, since these are extremely rich

in proteids, and supply all the nitrogen needed, without the necessity of swallowing the vast bulk of food which must be eaten in order to get it directly from plants.

Food Materials.—The above facts are best shown in the chemical analyses of food materials. Detailed diet studies have made it possible to construct meals based on the actual nutritive values of different foods, which shall give an adequate amount of nutriment to individuals of varying pursuits.

In the study of the dietaries it has been found that the essential points to be observed are the total amount of nitrogenous material (proteid) and the total fuel value of all the elements. It has been found that the fats and starches are largely interchangeable in the ordinary dietaries, hence their proportions are of less importance.

Relation of Diet to Work.—It must be remembered that energy is given off in the form of heat, and is used up in the body by the heart (as explained later), and by tissue activity. The external work accomplished by a man under different conditions is shown in the following table, together with the heat equivalents for this work. The amount of work accomplished is most readily expressed in foot-tons.*

ESTIMATES OF MECHANICAL WORK DONE BY A MAN IN A DAY.

	Foot-tons		Kilogrammetres.		Calories of Heat.
Light work, from	150 to 200	or	46,600 to 62,200	or	109 to 147
Average " "	300 " 350	"	93,300 " 108,800	"	219 " 258
Hard " "	450 " 500	"	139,900 " 155,500	"	329 " 366
Laborious " "	500 " 600	"	155,500 " 186,000	"	366 " 437

	Protein	Fats.	Carbo-hydrates.	Fuel Value.
Standard Diet, Atwater	127 gms.	113 gms.	494 gms.	3500 calories

* Each foot-ton represents the effort necessary to raise the equivalent of one ton to a height of one foot. This is equivalent to raising one pound to a height of two thousand feet. A kilogrammetre measures the effort necessary to raise one kilogram ($2\frac{1}{5}$ lbs.) to a height of one metre. ($3\frac{1}{3}$ ft.).

ANALYSES OF FOOD MATERIALS.

	Quantity required to yield 20 gms. N.	Quantity required to yield 300 gms. C	N. in 100 gms.	C. in 100 gms.	Proteid in 100 gms.	Fat in 100 gms.	Carbo-hydrate in 100 gms.	Water in 100 gms.	Fuel Value of one gram.
	gms.	gms.	gms.	gms.	gms.	gms.	gms.	gms.	Calories.
Cheese	400	770	5.0	39	31	31	....	34	4.223
Peas (dried)	570	840	3.5	35.7	22	2	55	15	3.608
Lean meat	590	2230	3.4	13.5	21	3.5	....	74	1.199
Entire wheat flour	870	750	2.3	40	14.2	1.9	70.6	12.1	3.652
White bread	1340	1200	1.5	25	9.5	1.2	52.8	35.4	2.651
Graham bread	1440	1150	1.4	26	8.5	1.8	55.9	32.3	2.805
Oatmeal	760	740	2.6	40.3	13	5.5	65	15	4.092
Eggs	1040	2040	1.9	14.7	11.5	12	....	75	1.595
Maize	1080	730	1.85	40.9	10.5	7	65	15	3.641
Rice	2040	820	0.9	36.6	5	1	83	10	3.586
Milk	3170	4250	0.6	7	4	4	5	85	.715
Potatoes	5000	2860	0.4	10.5	2	0.15	21	75	.836
Good butter	13000	430	0.15	69	1	90	....	8	7.645

In comparing these figures with the number of heat units in Atwater's standard diet it will be noticed that only about one-tenth of the energy value of the food is utilized for external work; the remaining nine-tenths are used up in doing the internal work of the body and in making good the heat losses. It has been estimated that in muscular work only one-third of the energy of the food is converted into mechanical work by the muscle, the remaining two-thirds being dissipated as heat.

CHAPTER XI.

THE DIGESTIVE ORGANS.

General Arrangement of the Alimentary Canal.—The alimentary canal is a tube which runs through the body from the lips to the posterior end of the trunk. It is lined by a soft reddish *mucous membrane* (easily seen inside the mouth), which is but a redder and moister sort of skin. Outside the mucous membrane are connective tissue and muscular layers, which strengthen the digestive tube and push the swallowed food along it. The mucous membrane is constructed to absorb dissolved nutritive substances; it soaks them up and passes them into blood or lymph vessels. Imbedded in this mucous membrane, or lying outside it, are hollow organs called *glands*; these glands make liquids which change food substances chemically so that they may be absorbed by the mucous membrane. The whole series of changes which any food material undergoes, between its reception by the mouth and its absorption by the alimentary mucous membrane, is spoken of as its *digestion*.

Various foodstuffs undergo different kinds of changes preliminary to absorption, and so we speak of different kinds of digestions; as that of starch, of fats, of albuminous bodies, and so forth.

Glands are, ordinarily, hollow organs which make or *secrete* peculiar fluids and pour them out on some free surface of the

body. They are very widely distributed; we find, for example, digestive glands of several kinds opening into the digestive tube, perspiratory glands opening on the skin, tear or *lachrymal glands* pouring out their secretion on the eyeball. Different glands have their cavities lined by different kinds of cells, and produce different secretions. In general all glands are built on one or the other of two primary structural plans, known as the *tubular* and the *racemose* (Fig. 45).

The Kinds of Glands.—All portions of the body making and pouring forth secretions are not technically called glands. In the peritoneum, which forms the inside lining of the abdominal cavity (p. 8), we find simply a thin membrane (*A*, Fig. 45), having on the side next the cavity which it surrounds a layer of cells (*a*) and on its deeper side a network of very fine blood-vessels (*c*) supported by connective tissue (*d*). This arrangement is also found in the pleuræ, the pericardium, and the synovial membranes, but is not the most common form of secreting tissue. In most cases the area of the surfaces necessary to secrete the amounts of the various fluids needed would be too great to be packed conveniently in the body by simply spreading out flat membranes. Accordingly, in most cases, a large area is obtained by folding the secreting surface in various ways so that a wide surface can be packed in a small bulk, just as a Chinese paper lantern when shut up occupies much less space than when extended, although the actual area of the paper in it remains the same. In a few cases the folding takes the form of protrusions into the cavity of the secreting organ (*C*, Fig. 45), but much more commonly the surface extension is attained by pitting or depressing the supporting or *basement membrane*, covered by its epithelium (*B*). Such a secreting organ is known as a true *gland*.

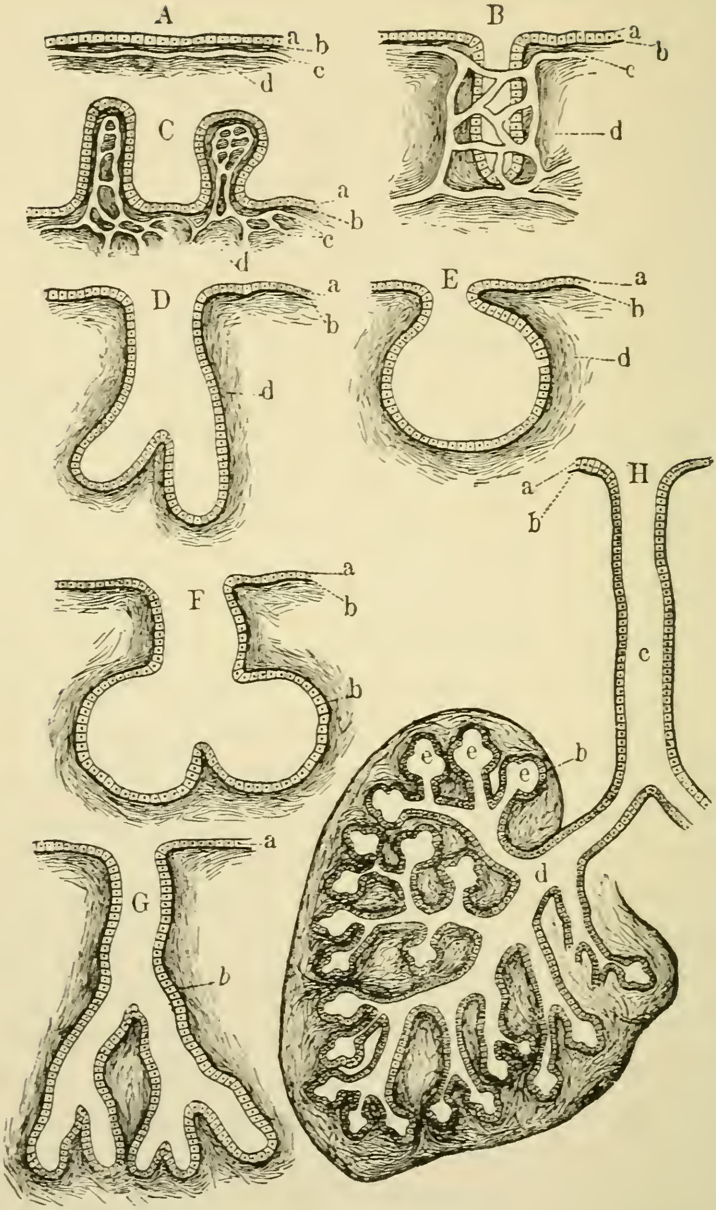

FIG. 45.—Forms of glands. *A*, a simple secreting surface; *a*, its epithelium; *b*, basement membrane; *c*, capillaries; *B*, a simple tubular gland; *C*, a secreting surface increased by protrusions; *E*, a simple racemose gland; *D* and *G*, compound tubular glands; *F*, a compound racemose gland. In all but *A*, *B*, and *C* the capillaries are omitted for the sake of clearness. *H*, half of a highly developed racemose gland; *c*, its main duct.

Forms of Glands.—In some cases the surface involutions are uniform in diameter, or nearly so (*B*, Fig. 45), and are known as *tubular*; examples are found in the lining coat of the stomach (Fig. 57), also in the skin (Fig. 109) where they form the *sweat-glands*. In other cases the involution swells out at its deeper end and becomes more or less sacculated (*E*); such glands are named *racemose* or *acinous*. The small glands of the skin which form the oily matter for the hairs (p. 227) are of this type. In both kinds the lining cells near the deeper end are commonly different in character from the rest, and around that part of the gland the finest and thinnest walled blood-vessels (*capillaries*) form a closer network. These deeper cells form the true secreting tissue of the gland, while the tube, lined with different cells, which leads from the secreting recesses to the surface on which the secretion is poured out, serves merely to drain it off and is known as the *duct* of the gland. When the duct is undivided the gland is *simple*; but when, as is more usual, it is branched and each branch has a true secreting chamber at its end the gland is compound, tubular (*G*), or racemose (*F*, *H*) as the case may be. In many cases the chief duct, in which the smaller ducts unite, is of considerable length, so that the secretion is poured out at some distance from the main mass of the gland.

A fully formed gland, *H*, is thus a complex structure, consisting primarily of a duct (*c*) ductules (*dd*) and secreting recesses (*ee*). The ducts and ductules are lined with protective cells which differ in character from the secreting cells lining the deepest parts. The cells lining the ultimate recesses differ in different glands, and produce different liquids; consequently, though all glands are built on much the same plan,

they make very varied secretions, according to the properties of their cells.

The Complexity of the Alimentary Canal.—We may now return to our immediate subject, the alimentary canal. This is not a simple tube, but presents several dilatations in its course; nor is it a comparatively straight tube, as diagrammatically represented in Fig. 1, but, being much longer than the body, much of it is packed away by being coiled up in the abdominal cavity.

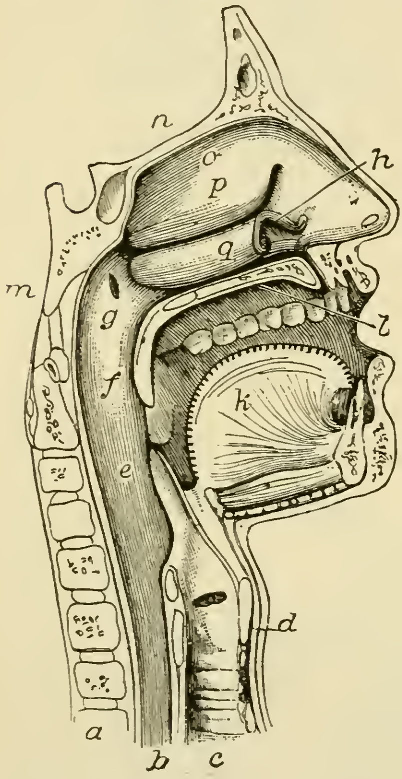

FIG. 46.—The mouth, nose, and pharynx, with the commencement of the gullet and larynx, as exposed by a section, a little to the left of the median plane of the head. *a*, vertebral column; *b*, gullet; *c*, windpipe; *d*, larynx; *e*, epiglottis; *f*, soft palate; *g*, opening of Eustachian tube; *k*, tongue; *l*, hard palate; *m*; the sphenoid bone on the base of the skull; *n*, the fore part of the cranial cavity; *o*, *p*, *q*, the turbinate bones of the outer side of the left nostril chamber.

Subdivisions of the Alimentary Canal.—The mouth opening leads into a chamber containing the teeth and tongue, named the *mouth chamber* or *buccal cavity*. This primary dilatation is separated by a constriction (*the isthmus of the fauces*) at the back of the mouth, from another cavity, the *pharynx* or *throat chamber*, which narrows again at the top of the neck into the *gullet* or *œsophagus*. The latter runs as a comparatively narrow tube through the thorax, and then, passing through the diaphragm, dilates in the upper part of the abdominal cavity to form the *stomach* (see Fig. 1). Be-

yond the stomach the channel again narrows to form a long and greatly coiled tube, the *small intestine*, which terminates by opening into the *large intestine*; this, though shorter, is wider, and ends by opening on the exterior.

The Mouth Cavity (Figs. 46 and 47) is bounded in front and on the sides by the lips and cheeks, below by the tongue

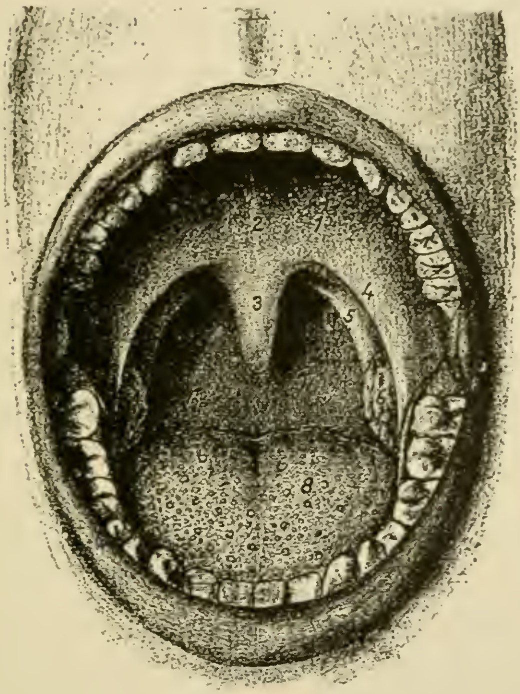

FIG. 47.—1, soft palate; 2, its median ridge; 3, uvula; 4, anterior, 5, posterior pillar of fauces; 6, tonsil; 7, posterior wall of pharynx; 8, tongue.

(*k*), and above by the *palate*, which consists of an anterior part (*l*) supported by bone and called the *hard palate*, and a posterior (*f*) containing no bone, and called the *soft palate*. The two can be distinguished by applying the tip of the tongue to the roof of the mouth and drawing it backwards. The hard palate forms the partition between the mouth and nose. The soft palate arches down at the back of the mouth,

hanging like a curtain between it and the pharynx, as can be seen on holding the mouth open in front of a looking glass. From the middle of its free border a conical process, the *uvula*, hangs down.

The Teeth.—Immediately within the cheeks and lips are two semicircles, formed by the borders of the upper and lower jaw-bones, and covered by the *gums*, except at intervals along their edges where teeth are implanted. During life two sets of teeth are developed: the first or *milk set* appear soon after birth and are shed during childhood, when the second or *permanent set* appear.

The General Structure of a Tooth.—The teeth differ in minor points from one another, but in all, three parts are distinguishable: * one, seen in the mouth and called the *crown* of the tooth; a second, imbedded in the jaw-bone and called the *root* or *fang;* and between the two, embraced by the edge of the gum, a narrowed portion, the *neck* or *cervix*. By differences in their forms and uses the teeth are divided into *incisors*, *canines*, *bicuspids*, and *molars*, arranged in a definite order in each jaw. Beginning at the middle line we find in each half of each jaw, successively, two incisors, one canine, and two molars in the milk set, making twenty altogether in the two jaws. The teeth of the permanent set are thirty-two in number, eight in each half of each jaw, viz.—beginning at the middle line—two incisors, one canine, two bicuspids, and three molars. The bicuspids of the permanent set replace the molars of the milk set, while the permanent molars are new teeth added as the jaw grows. The last permanent molars are often called the *wisdom teeth*.

* A number of teeth can be readily obtained from a dentist, and will be found of great use in connection with this lesson.

Characters of Individual Teeth.—The *incisors* or *cutting teeth* (Fig. 48) are adapted for cutting the food. Their crowns are chisel-shaped and have sharp horizontal cutting edges which become worn away by use, so that they are bevelled off at the back in the upper row and at the front in the lower. Each has a single long fang. The *canines* (*dog teeth*) (Fig. 49) are somewhat larger than the incisors. Their crowns are thick and somewhat conical, having a central point or *cusp* on the cutting edge. In dogs and cats the canines are very long and pointed, and adapted for seizing and holding prey. The *bicuspids* or *premolars* (Fig. 50) are


FIG. 48.


FIG. 49.


FIG. 50.


FIG. 51.

FIG. 48.—An incisor tooth.
FIG. 49.—A canine or eye tooth.
FIG. 50.—A bicuspid tooth seen from its outer side; the inner cusp is accordingly not visible.
FIG. 51.—A molar tooth.

rather shorter than the canines and their crowns are cuboidal. Each has two cusps, an outer and an inner. The *molar teeth* or *grinders* (Fig. 51) have large crowns with broad surfaces, and four or five projecting tubercles which roughen them and make them better adapted to crush the food. Each has usually several fangs. The *milk teeth* differ only in minor points from those of the same names in the permanent set.

The Structure of a Tooth.—If a tooth is broken open a cavity extending through both crown and fang will be found in it. This is filled during life with a soft pulp, containing blood-vessels and nerves and known as the "pulp cavity."

The hard parts of the tooth disposed around the pulp cavity consist of three different tissues. Of these, one, *dentine* or ivory, immediately surrounds the cavity and makes up most

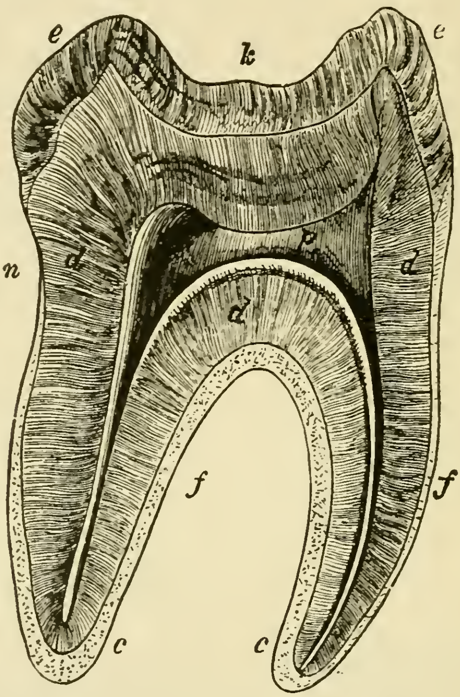

FIG. 52.—Longitudinal section of a molar tooth. *k*, crown ; *n*, neck ; *f*, fangs ; *e*, enamel ; *d*, dentine ; *c*, cement ; *p*, pulp cavity.

of the bulk of the tooth ; covering the dentine on the crown is *enamel*, the hardest tissue in the body,* and on the fang the *cement*, which is a thin layer of bone.

The pulp cavity opens below by a narrow aperture at the tip of the fang, or at the tip of each fang if the tooth has more than one. Through these openings its blood-vessels and nerves enter.

Hygiene of the Teeth.—The teeth should be thoroughly cleansed night and morning, by means of a tooth-brush dipped in tepid water. Once a day soap should be used, or a

* Enamel will strike fire with flint.

little very finely powdered chalk sprinkled on the brush. The weak alkali of the soap or chalk is useful. A large proportion of a tooth consists of carbonate and phosphate of calcium, which readily dissolve in weak acids; decomposing food particles lodged between the teeth develop acids, which eat away the tooth slowly but surely. Hence all food particles should be carefully removed from between the teeth; as this cannot always be effected completely it is important to brush the teeth with alkaline substances which will neutralize and render harmless any acid.* Good manners forbid the public use of a tooth-pick, but on the earliest privacy after a meal a wooden or quill tooth-pick, or better dental silk, should be employed systematically and carefully to dislodge all food remnants which may have remained wedged between the teeth.

Once a slight cavity has been formed, the process of decay is apt to go on very fast; first, because the exposed deeper layer of the tooth is more easily dissolved than its natural surface, and second, because the little pit forms a lodging-place for bits of food, which, in decomposing through the action of bacteria, form acids and hasten the corrosion. Small eroded cavities are very apt to be overlooked; the teeth should, therefore, be thoroughly examined two or three times a year by a dentist.

The Tongue (Fig 53) is a muscular and highly movable organ, covered by mucous membrane and endowed not only with a delicate sense of touch but with the sense of taste. Its root is attached to the hyoid bone (p. 20). The mucous membrane covering the upper surface of the tongue is rough-

* Acid medicines should always be sucked through a glass tube and swallowed with as little contact as possible with the teeth. After each dose the mouth should be thoroughly rinsed with water.

ened by numerous minute elevations or *papillæ*, of which there are three varieties. The *circumvallate papillæ* are the

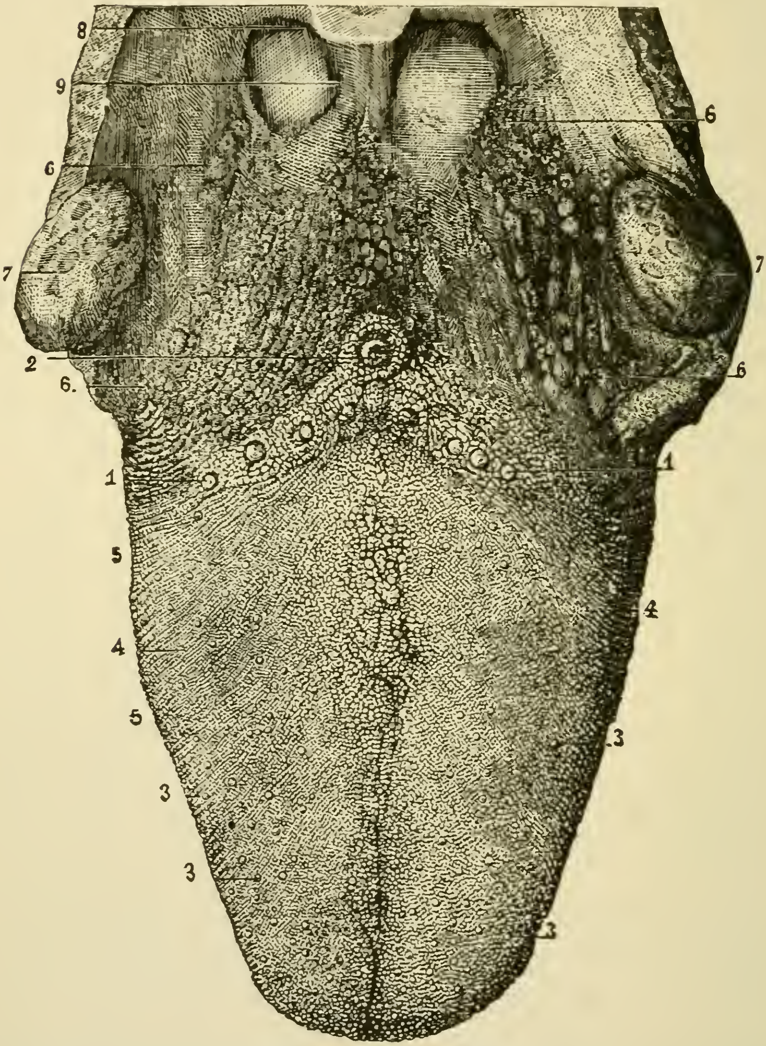

FIG. 53.—The upper surface of the tongue. 1, 2, circumvallate papillæ; 3, fungiform papillæ; 4, filiform papillæ; 6, mucous glands.

largest and fewest, and lie near the root of the tongue, arranged in the form of a V, with its open angle turned to-

wards the lips. The *fungiform papillæ* are rounded masses attached by narrower stems. They are found all over the middle and fore part of the upper surface of the tongue, and during life are readily recognized as red dots, more deeply colored because more richly supplied with blood than the rest of the mucous membrane. The *filiform papillæ* are pointed elevations scattered all over the upper surface of the tongue, except near its root. On our tongues, they are the smallest and most numerous.*

What a "Furred Tongue" Indicates.—In health the surface of the tongue is moist, covered by little "fur," and in childhood is of a red color. In adult life the natural color of the tongue is less red, except around the edges and tip; a bright red glistening tongue is then usually a symptom of disease. When the digestive organs are deranged the tongue is commonly covered with a thick yellowish coat and there is frequently a "bad taste" in the mouth.† All the parts of the alimentary mucous membrane are in close physiological connection, and anything disordering the stomach is likely to produce a "furred tongue," which in most cases may be taken as indicating something wrong with the deeper parts of the digestive tract.

The Salivary Glands.—The saliva, which is poured into the mouth and moistens it, is secreted by three pairs of glands, the *parotid*, the *sublingual*, and the *submaxillary.*

* The filiform papillæ are very large on the tongue of the cat, where they may readily be seen and felt. They are large in nearly all caronivrous animals, serving to scrape or lick clean bones, etc. Tamed tigers have been known to draw blood by licking the hand of their master.

† The fur of the tongue consists of some mucus, a few cells shed from its surface, and numerous vegetable microscopic organisms belonging to the group of *Bacteria.*

(Fig. 55.) The parotid glands lie close in front of the ear; each sends its secretion into the mouth by a duct, which opens inside the cheek opposite the second upper molar tooth. In the disease known as *mumps** the parotid glands are inflamed and enlarged. The sublingual glands lie under the tongue

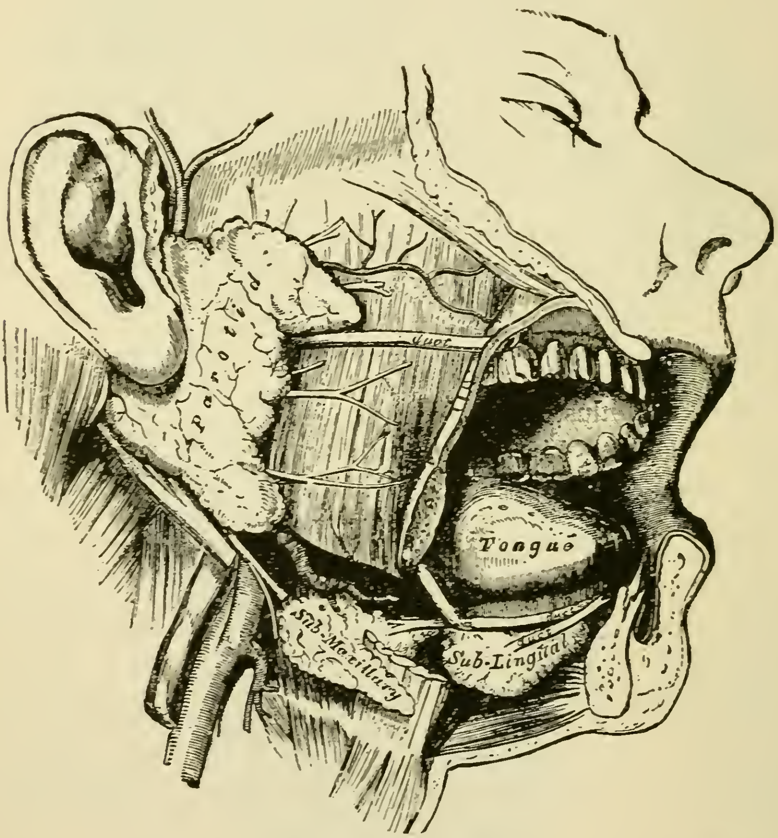

Fig. 55.—The salivary glands. One side of the lower jaw has been removed, and the face dissected, in order to show the salivary glands of the right side.

between the halves of the lower jaw-bone, and their ducts open in the front of the mouth beneath the tongue. The sub-

* Technically, *parotitis.*

maxillary glands lie beneath the floor of the mouth behind the sublingual near the angle of the jaw.

The Fauces is the name given to the passage which can be seen at the back of the mouth leading from it into the pharynx, below the soft palate.* It is bounded above by the soft palate and the uvula, below by the root of the tongue, and on the sides by muscles, covered by mucous membrane and reaching from the soft palate to the tongue. The muscles cause folds known as the *pillars of the fauces.* Each fold divides near the tongue, and in the hollow between its divisions lies a *tonsil* (Fig. 53), a soft rounded body about the size of an almond containing numerous minute glands which form mucus.

Enlarged Tonsils.—The tonsils sometimes become enlarged during a cold or sore throat. Occasionally the enlargement is permanent and causes much annoyance. The tonsils can, however, be readily removed without danger, and this is the treatment usually adopted in such cases.

The Pharynx or Throat Cavity (Fig. 46).—This portion of the alimentary canal may be described as a conical bag with its broad end turned up toward the base of the skull and the other end narrowed into the gullet. Its front or ventral wall is imperfect, presenting apertures which lead into the nose, the mouth, and (through the larynx and windpipe) into the lungs. Except when food is being swallowed the soft palate hangs down between the mouth and pharynx; during swallowing (*deglutition*) it is raised into a horizontal position, and separates the upper or *nasal portion* of the pharynx from the rest. Through this upper part only air

* Observe for yourself with the help of a looking glass.

passes,* entering it from the posterior ends of the two nostril chambers. Through the lower portion both food and air pass, one on its way to the gullet (*b*, Fig. 46), the other through the larynx (*d*) to the windpipe (*c*). When a morsel of food "goes the wrong way" it takes the latter course. Opening into the upper portion of the pharynx on each side is an Eustachian tube (*g*). At the root of the tongue, over the opening of the larynx, is a plate of cartilage, the *epiglottis* (*e*), which can be seen if the mouth is widely opened and the back of the tongue pressed down by the handle of a spoon. During swallowing the epiglottis is pressed down like a lid over the opening of the air-tube and helps to keep food from entering it. The pharynx is lined by mucous membrane and has muscles in its walls which, by their contraction, drive the food on.

The Œsophagus or Gullet is a tube which commences at the lower termination of the pharynx and, passing on through the neck and chest, ends below the diaphragm in the stomach. In the neck it lies close behind the windpipe.

The Stomach (Fig. 56) is a curved conical elastic bag placed transversely in the upper part of the abdominal cavity.† Its larger end is turned to the left and lies close beneath the diaphragm; the gullet (*d*) opens into its upper border, through the *cardiac orifice* at *a*. The narrower right end is continuous with the small intestine and communicates

* During a severe attack of vomiting the soft palate often acts imperfectly in closing the passage between gullet and nostrils: hence some of the ejected matter not unfrequently is expelled through the nose

† The general anatomical arrangement of the stomach, and its connections with the gullet and intestine, may be readily shown on the body of a puppy, kitten, or rat which has been killed by placing it for five minutes in a small box containing also a sponge soaked with chloroform.

with it through the *pyloric orifice* (*c*). The pyloric end of the stomach is separated from the diaphragm by the liver (see Fig. 4). When moderately distended the stomach is about twelve inches long, four inches across at its widest part, and contains about three pints.

The Glands of the Stomach.—The mucous membrane

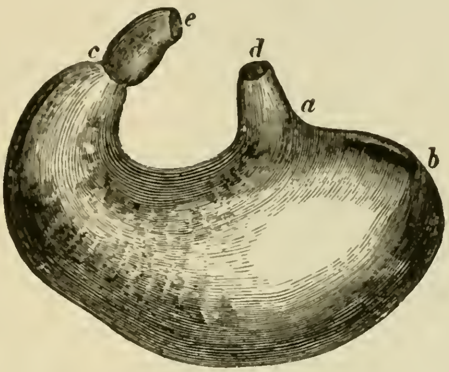

FIG. 56.—The stomach. *d*, lower end of the gullet; *a*, position of the cardiac aperture; *b*, the fundus; *c*, the pylorus; *e*, the first part of the small intestine; along *a*, *b*, *c*, the great curvature; between the pylorus and *d*, the lesser curvature.

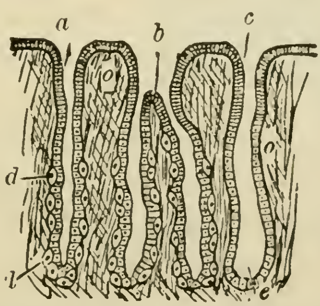

FIG. 57.—A thin section through the gastric mucous membrane, perpendicular to its surface, magnified about 25 diameters. *a*, a simple peptic gland; *b*, a compound peptic gland; *c*, a mucous gland.

lining the stomach is seen, with a magnifying glass, to be covered with shallow pits. A microscope shows on the bottom of each of these pits the openings of several minute tubes,

the gastric glands, which lie imbedded in the mucous membrane (Figs. 57 and 58) and secrete the *gastric juice*.

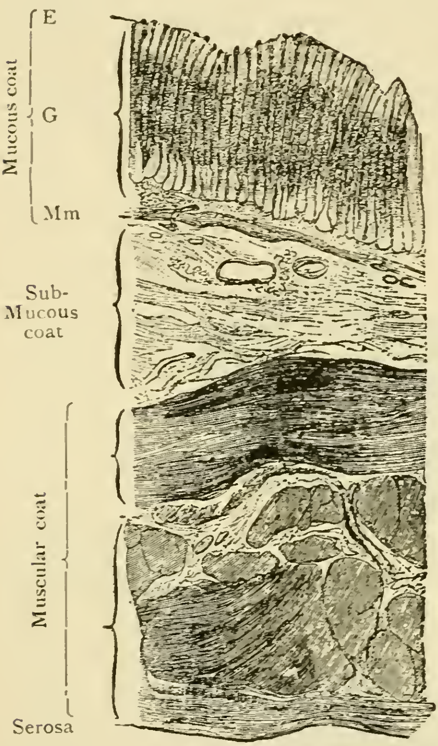

FIG. 58.—Wall of human stomach. *E*, epithelium; *G*, glands: *Mm*, muscularis mucosæ.

The Muscular Coat of the Stomach lies outside the mucous membrane, and is made up (Fig. 34 and Fig. 48*a*) of plain muscular tissue, whose fibres run in different directions. By its contractions it stirs up the food and mixes it with the gastric juice. Around the pyloric orifice of the stomach is a thick ring of muscle (the *pyloric sphincter*), which usually by contracting closes the passage between the stomach and the commencement of the small intestine. During digestion in the stomach the pyloric sphincter relaxes from time to time, and allows food, more or less digested, to pass on into the intestine.

Palpitation of the Heart.—The cardiac end of the stomach lies close below, and the heart immediately above, the diaphragm. Over-distension of the stomach by gas (*flatulence*), which is one of the symptoms accompanying indigestion, may press up the diaphragm and interfere with the proper working of the thoracic organs, causing feelings of oppression in the chest, or palpitation of the heart.

The Small Intestine commences at the pylorus and ends, after many windings, in the large intestine. It is about twenty feet (six meters) long and about two inches (five centimeters) wide at its gastric end, narrowing to about two thirds of that width at its lower portion. Externally there are no lines of subdivision on the small intestine, but anatomists arbitrarily describe it as consisting of three parts, of which the first ten or twelve inches is the *duodenum*,* the succeeding two fifths of the remainder the *jejunum*, and the rest the *ileum*.

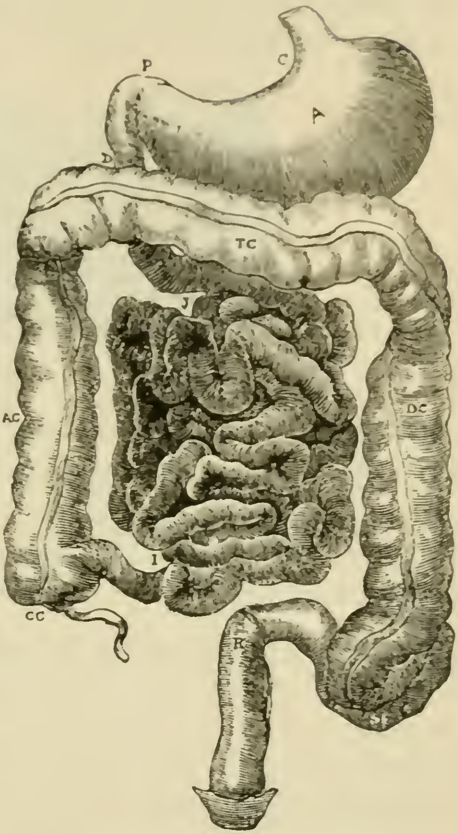

Fig. 59.—Diagram of abdominal part of alimentary canal. *C*, the cardiac, and *P*, the pyloric end of the stomach; *D*, the duodenum; *J*, *I*, the convolutions of the small intestine; *CC*, the cæcum with the vermiform appendix; *AC*, ascending, *TC*, transverse, and *DC*, descending colon; *R*, the rectum.

The Mucous Coat of the Small Intestine is pink, soft, and extremely vascular. Throughout a great portion of the length of the tueb it is raised into permanent folds in the form of crescentic ridges (Fig. 60). These folds (*valvulæ conniventes*) run transversely for a greater or less distance round the intestine. They are first found about two inches from the pylorus, and are most thickly set and largest

* Duodenum signifies literally twelve, and is applied here because this portion is about twelve fingerbreadths long.

in the upper half of the jejunum. In the lower half they become gradually less conspicuous, and finally disappear altogether about the middle of the ileum. The folds of the

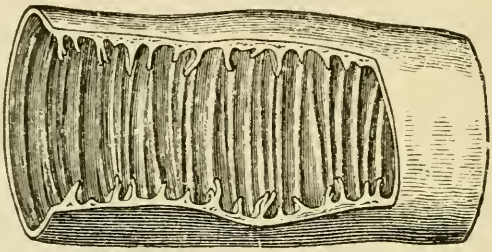

FIG. 60.—A portion of the small intestine opened to show the *valvulæ conniventes*.

mucous membrane serve greatly to increase its surface both for absorption and secretion, and also to delay the food in its passage; it collects in the hollows between them, and so is longer exposed to the action of the digestive liquids.

The Villi.—Examined closely with the eye or, better, with a hand lens, the mucous membrane of the small intestine is seen to be shaggy and covered everywhere (both over the valvulæ conniventes and between them) with closely packed minute elevations standing up somewhat like the "pile" on velvet and known as the *villi* (Fig. 61). In structure a villus is somewhat complex. Beneath the covering of a single layer of cells the villus consists of a framework of connective tissue supporting the more essential constituents. Near the surface is a network of plain muscular tissue. In the centre is an offshoot of the lymphatic or absorbent system, sometimes in the form of a single vessel with a closed dilated end, and sometimes as a network formed by two main vessels with cross-branches. During digestion these lymphatics are filled with a milky white liquid absorbed from the intestines, and are accordingly called the *lacteals*. They communicate with larger branches in the outer coats of the intestine, which

unite to form the trunks of the main lymphatic system. Finally, in each villus, outside its lacteals and beneath its muscular layer, is a close network of blood-vessels.

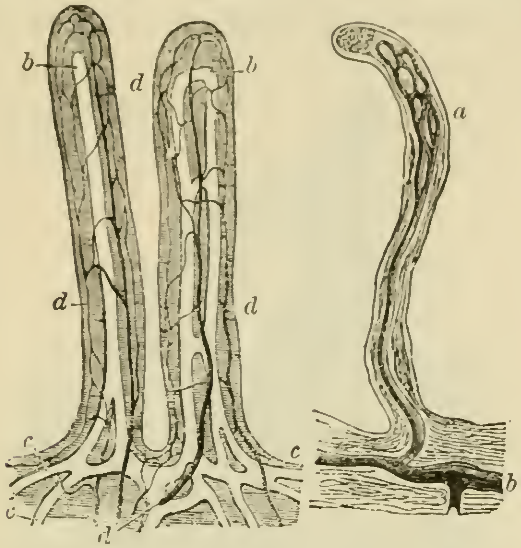

FIG. 61.—Villi of the small intestine, magnified about 80 diameters. In the left-hand figure the lacteals, *a*, *b*, *c*, are filled with white injection; *d*, blood-vessels. In the right-hand figure the lacteals alone are represented, filled with a dark injection. The epithelium covering the villi, and their muscular fibres are omitted.

The Glands of the Small Intestine open on the surface of the small intestine between the bases of the villi and are called the *crypts of Lieberkühn* (Fig. 62). Each is a simple unbranched tube, lined by a single layer of cells.

The Muscular Coat of the Small Intestine, lying outside the mucous coat, is composed of plain muscular tissue, disposed in two layers, an inner circular and an outer longitudinal. By their combined and alternating contractions they produce annular constrictions of the intestine, which slowly travel from the stomach downward, one after another, and thereby force the digesting food along the tube. This movement is called *peristalsis*.

The Large Intestine (Fig. 59), forming the final portion

of the alimentary canal, is about 5 feet (1.5 meters) long, and varies in diameter from 2½ to 1½ inches (6–4 centimeters). Anatomists describe it as consisting of the *cæcum* (CC) with its *vermiform appendix*, the *colon* (AC, TC, DC), and the *rectum*

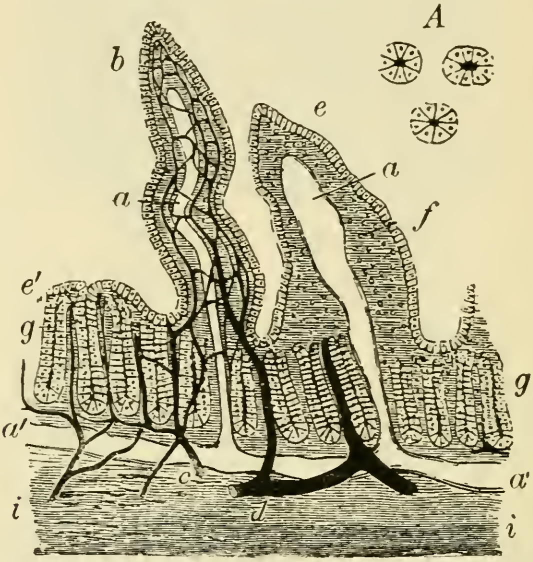

FIG. 62.—Vertical section of the intestinal mucous membrane of the rabbit. Two villi are represented, in one of which the dilated lacteal alone is shown, in the other the blood vessels and lacteal are both seen injected, the lacteal white, the blood vessels dark; *a*, the lacteal vessels of the villi; *a'*, horizontal lacteal, which they join; *b*, capillary blood vessels in one of the villi; *c*, small artery; *d*, vein; *e*, the epithelium covering the villi; *g*, tubular glands or crypts of Lieberkühn, some divided down the middle, others cut more irregularly; *i*, the submucous layer. *A*, cross-section of three tubular glands more highly magnified.

(R). The small intestine opens into the side of the large, some distance from its closed end; the cæcum is that part of the large intestine which extends beyond the communication. From it projects the *vermiform appendix*, a narrow tube not thicker than a lead pencil, and about 4 inches (10 centimeters) long. It is a residual structure of considerable importance in some of the lower animals. Its contents are ordinarily the same as those of the cæcum. It is therefore frequently the receptacle of grape seeds, etc., which apparently do no harm. It is sometimes the seat of an inflammation

(*appendicitis*) due to bacterial activity under favoring conditions. The colon commences on the right side of the abdominal cavity where the small intestine communicates with the large, runs up for some distance on that side (*ascending colon*), then crosses the middle line (*transverse colon*) below the stomach, and turns down (*descending colon*) on the left side. In the lower left side of the abdomen it makes an S-shaped

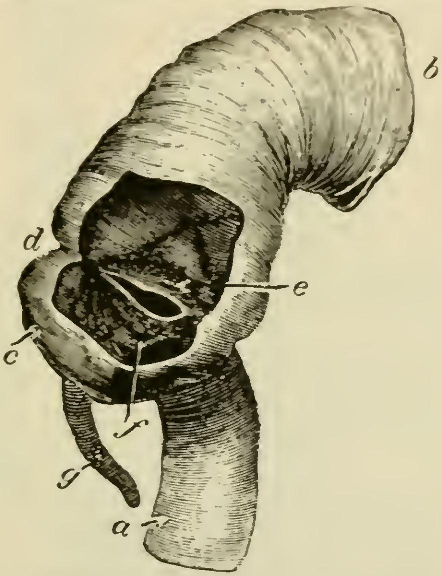

FIG. 63.—The ileo-cæcal valve. *a*, ileum ; *b*, ascending colon ; *c*, cæcum ; *d*, junction of the cæcum and colon ; *e* and *f*, loose folds of the mucous membrane, forming the ileo-cæcal valve ; *g*, vermiform appendage.

bend known as the *sigmoid flexure* ; from this the *rectum* proceeds to the opening by which the intestine communicates with the exterior. The mucous coat of the large intestine possesses no villi nor valvulæ conniventes ; it contains numerous closely set glands much like the crypts of Lieberkühn.

The Ileo-cæcal Valve.—Where the small intestine joins the large, there is a valve formed by two flaps of the mucous membrane sloping down into the colon, and so arranged as to allow matters to pass readily from the ileum into the large intestine, but not the reverse way.

The Liver.—Besides the secretions formed by the glands imbedded in its walls, the small intestine receives those of two large glands, the liver and *pancreas*, which lie in the abdominal cavity. The ducts of both open, by a common aperture, into the duodenum about 4 inches (10 centimeters) from the pylorus.

The liver is the largest gland in the body, weighing from 50 to 60 ounces (1400 to 1700 grams). It is situated in

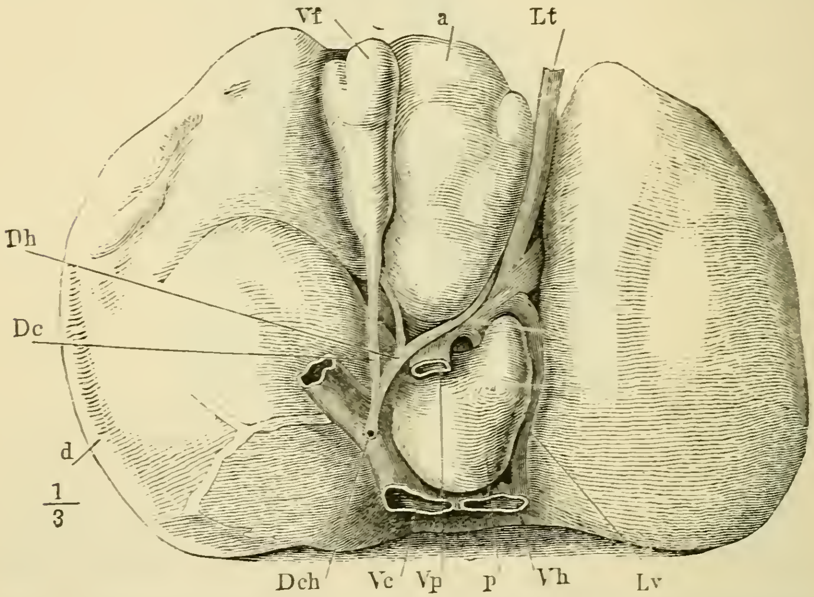

FIG. 64.—The under surface of the liver. *d*, right, and *s*, left lobe; *Vh*, hepatic vein; *Vp*, portal vein; *Vc*, vena cava inferior; *Dch*, common bile duct; *Dc*, cystic duct; *Dh*, hepatic duct; *Vf*, gall bladder.

the upper part of the abdominal cavity (*le*, *le'*, Fig. 4), rather more on the right than on the left side, immediately below the diaphragm. The liver is of dark reddish-brown color, and of soft friable texture. The vessels carrying blood to the liver (Fig. 64) are the *portal vein* (*Vp*), and the *hepatic artery*; both enter it at a groove on its under side, where a duct also passes out from each half of the organ. The ducts unite to form the *hepatic duct* (*Dh*),

which meets the *cystic duct* (*Dc*), proceeding from the *gall-bladder* (*Vf*), a pear-shaped sac in which the *bile* or *gall*

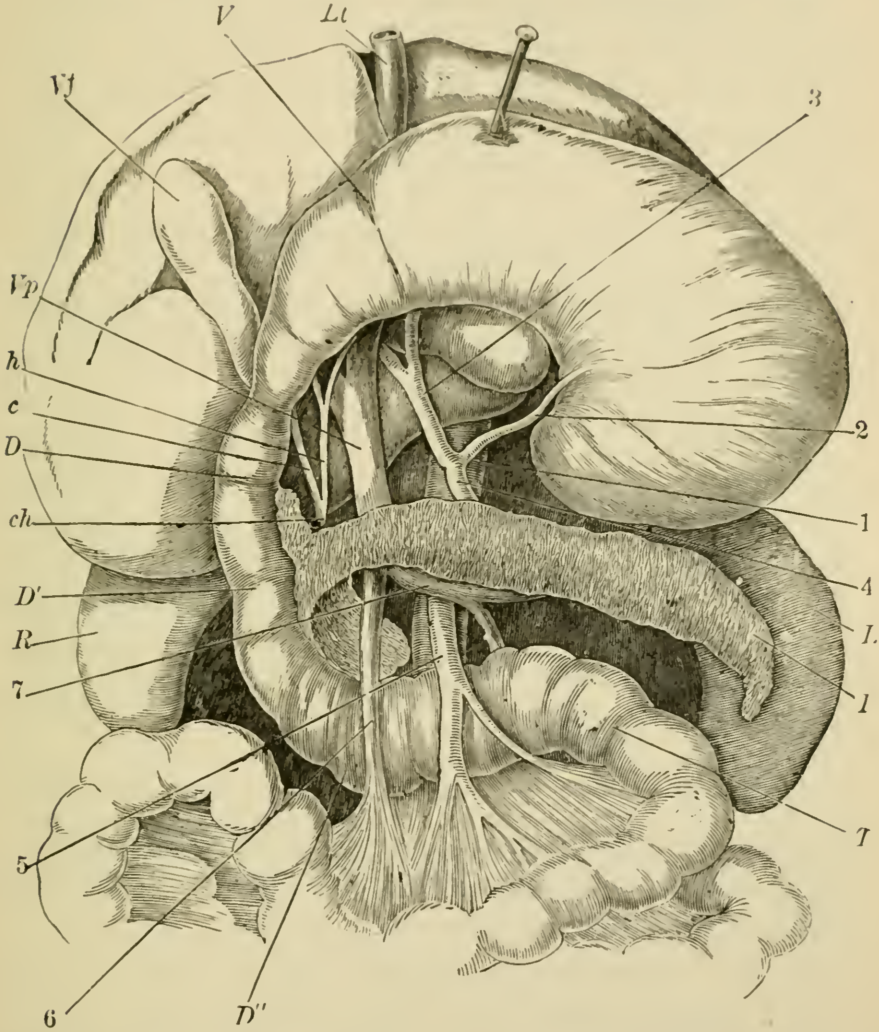

FIG. 65.—The stomach, pancreas, liver, and duodenum, with part of the rest of the small intestine and the mesentery; the stomach and liver have been turned up so as to expose the pancreas. *V*, stomach; *D*, *D'*, *D''*, duodenum; *L*, spleen; *P*, pancreas; *R*, right kidney; *T*, jejunum; *Vf*, gall bladder; *h*, hepatic duct; *c*, cystic duct; *ch*, common bile duct; 1, aorta; 2, an artery (left coronary) of the stomach; 3, hepatic artery; 4, splenic artery; 5, superior mesenteric artery; 6, superior mesenteric vein; 7, splenic vein; *Vp*, portal vein.

formed by the liver accumulates when food is not being digested in the intestine. The *common bile duct* (*Dch*), formed

by the union of the hepatic and cystic ducts, opens into the duodenum.

The Functions of the Liver.—The size of the liver suggests that it has important functions in the body. It receives all the blood from the stomach and intestines (the portal system). Its cells destroy old red corpuscles. They also take out of the blood excess of sugar and store it up in the form of a kind of animal starch (*glycogen*), which they later dole out again as sugar when the blood needs it. Experiments suggest that the liver cells bring about the final oxidation of nitrogenous materials into urea, in which form they are excreted by the kidneys.

The Pancreas * is a compound racemose gland. It is an elongated soft organ of a pinkish-yellow color, lying along the lower border of the stomach. Its right end is embraced by the duodenum, which there makes a curve to the left. A duct drains it and joins the common bile duct close to its intestinal opening. The pancreas secretes a watery-looking liquid, much like saliva in appearance, which is of great importance in digestion.

* Butchers sell two kinds of sweetbread, known as the belly sweetbread and the neck or heart sweetbread. The former is the pancreas; the latter is the *thymus*, an organ of doubtful function, found only in young animals, and lying at the bottom of the neck and upper part of the chest in front of the windpipe.

CHAPTER XII.

DIGESTION.

The Object of Digestion.—A few of the foodstuffs which we eat are in solution and ready to soak at once into the lymphatics and blood vessels of the alimentary canal; others, such as a grain of salt, though not dissolved when put into the mouth, are readily soluble in the liquids found in the alimentary canal and need no further digestion. In the case of many most important foodstuffs, however, as milk, special chemical changes have to be brought about to make them capable of absorption. The different secretions poured into the alimentary tube act in various ways upon different foodstuffs, dissolving some and chemically changing others, until at last all are in a condition in which they can be taken up into the lymph and blood-vessels for transference to distant parts of the body.

Digestive Ferments.—The chemical changes necessary to make the foods absorbable are accomplished almost wholly by the action of various organic ferments, each with a special power adapted to the digestion of a particular foodstuff. *Ptyalin*, found in saliva, *pepsin* and *rennin* in gastric juice, *trypsin*, *amylopsin*, and *steapsin* in the pancreatic juice, and *invertin* in the intestinal juice, are the most important of these.

The Saliva, the first solvent poured upon the food, is a mixture of pure saliva from the salivary glands with the

mucus secreted by the membrane lining the mouth. This *mixed saliva* is a colorless, cloudy, feebly alkaline liquid.

The Uses of Saliva are mainly physical and mechanical. It keeps the mouth moist and allows us to speak with comfort. Most young orators know the distress occasioned by the suppression of the salivary secretion through nervousness, and the imperfect efficacy under such circumstances of the traditional glass of water placed beside public speakers. The saliva also enables us to swallow dry food; such a thing as a cracker when chewed would give rise merely to a heap of dust, impossible to swallow, were not the mouth cavity kept moist.* The saliva further dissolves such bodies as salt and sugar when taken into the mouth in a solid form, and enables us to taste them; undissolved substances are not tasted, a fact which any one can verify for himself by wiping his tongue dry and placing a fragment of sugar upon it.

Chemical Action of the Saliva.—In addition to these physical actions, the saliva effects a chemical change on an important foodstuff, due to the presence of the ferment ptyalin. Starch (although it swells up greatly in hot water) is insoluble and cannot be absorbed from the alimentary canal. Ptyalin adds chemically a portion of water to the starch and thus changes it into the readily soluble and absorbable maltose, a form of sugar.

$$\underset{\text{Starch.}}{2C_6H_{10}O_5} + \underset{\text{Water.}}{2H_2O} = \underset{\text{Maltose.}}{2C_6H_{12}O_6}.$$

* This fact used to be taken advantage of in the East Indian rice ordeal for the detection of criminals. The guilty person, believing firmly that he cannot swallow the parched rice given him, and sure of detection, is apt to have his salivary glands paralyzed by fear, and so does actually become unable to swallow the rice; while in those with clear consciences the nervous system, acting normally, excites the usual reflex secretion, and the dry food causes no difficulty of deglutition.

The Influence of Saliva in Promoting Digestion in the Stomach.—It changes starch into maltose most rapidly when no acid is present. When the food passes from the mouth to the stomach the saliva's action is retarded by the acidity of the gastric juice. Indirectly, however, the saliva promotes digestion in the stomach. Weak alkalies stimulate the gastric glands to pour forth more abundant secretion,* and the alkaline saliva acts in this way. This is one reason why food should be well chewed before being swallowed; its taste, and the movements of the jaws, excite a more abundant salivary secretion, and the saliva, when swallowed, helps to stimulate the stomach.

Swallowing or Deglutition.—A mouthful of solid food is broken up by the teeth and rolled about the mouth by the tongue until it is thoroughly mixed with saliva and made into a soft pasty mass. The muscles of the cheeks keep it from getting between them and the gums.† The mass is finally sent on from the mouth to the stomach by the process of *deglutition*, which occurs in three stages. The *first stage* includes the passage from the mouth into the pharynx. The food being collected into a heap on the tongue, the tip of that organ is placed against the front of the hard palate, and then the rest of the tongue is raised from before back, so as to compress the food mass between it and the palate and drive it through the fauces. This much of the act of swallowing is voluntary, or at least is under the control of the will, although it commonly takes place unconsciously. The *second stage of deglutition* is that in which the food passes through the pharynx;

* Hence the efficacy of a little carbonate of soda or apollinaris water taken before meals, in some forms of dyspepsia.

† Persons with facial paralysis have from time to time to press out with the finger food which has collected outside the gums, where it can neither be chewed nor swallowed.

this is the most rapid part of its progress, since the pharynx has to be emptied quickly so as to clear the opening of the air-passages for breathing purposes. The food mass, passing back over the root of the tongue, pushes down the epiglottis; at the same time the larynx (or voice-box at the top of the windpipe) rises to meet the epiglottis, and thus aids in closing the passage to the lungs.* The soft palate is raised at the same time to close the passage into the nose (see Fig. 46). As the final step the isthmus of the fauces is closed as soon as the food has passed, by the contraction of the muscles on its sides and the elevation of the root of the tongue. As all passages out of the pharynx except the gullet are thus blocked, the pharyngeal muscles, by contracting, can squeeze the food only into the œsophagus. The muscular movements concerned in this part of deglutition are all excited without the intervention of the will; the food, by touching the mucous membrane of the pharynx, produces involuntarily the proper action of the swallowing muscles.† Indeed, many persons after having got the mouth completely empty cannot perform the movements of the second stage of deglutition at all. On account of the involuntary nature of the contractions of the pharynx the isthmus of the fauces forms a sort of Rubicon; food that has entered the pharynx must be swallowed, even though the swallower learns immediately that he is taking poison. The *third stage of deglutition* is that in which the food is passing along the gullet, and is comparatively slow. Even liquid substances do not fall or flow down this tube, but have their passage more or less controlled by its muscular coats, which grip

* The raising of the larynx during swallowing can be readily felt by placing the finger on its large cartilage forming "Adam's apple" in the neck.

† The process is what is known as a reflex action. See Chap. XX.

the successive portions swallowed and pass them on. Hence the possibility of performing the apparently wonderful feat of drinking a glass of water while standing upon the head: people forget that one sees the same thing done every day by horses and other animals which drink with the pharyngeal end of the gullet lower than the stomach.

The Gastric Juice.—The food having entered the stomach is exposed to the action of the gastric juice, which is a thin colorless or pale yellow liquid of a strongly acid reaction. It contains, beside water, salts and mucus, *free hydrochloric acid* (about 0.2 per cent), and a ferment *pepsin*, which in acid liquids has the power of converting ordinary proteids into closely allied substances called *peptones*. It also dissolves solid proteids, changing them at the same time into peptones.

Peptones.—Ordinary proteids are typical examples of what are called "colloids," that is to say, substances which do not readily pass through moist animal membranes. Peptones are a kind of proteid which does readily pass through such membranes, and are, therefore, capable of absorption from the alimentary canal. (See *Dialysis*, p. 145.)

The change to peptone is solely for the purpoes of absorption, since peptone is not found in the blood, and when introduced acts as a poison. Peptone is chiefly represented in the blood by the blood proteids serum, albumin and serum globulin. This change from the diffusible peptone back to a non-diffusible proteid is supposed to be due to the action of the epithelial cells of the intestine through which the absorption takes place. It is thus seen that the digestion of proteids is but a step toward the production of the proteids of the blood, which form the real nitrogenous food of the tissue.

Gastric Digestion.—In the stomach the onward progress of the food is stayed for some time. The pyloric sphincter

remaining contracted closes the aperture leading into the intestine, and the irregularly disposed muscular layers of the stomach keep its semi-liquid contents in constant movement, by which all portions are thoroughly mixed with the secretion of its glands. In the stomach, part of the proteid of the food is dissolved and turned into peptones. Certain mineral salts (as phosphate of lime, of which there is always some in bread), which are insoluble in water but soluble in dilute acids, are also dissolved in the stomach. On the other hand, the gastric juice has no action upon starch, nor does it digest oily substances. By the solution of the white fibrous connective tissues the disintegration of animal foods, commenced by the teeth, is carried much further in the stomach; and the food mass, mixed with much gastric secretion, becomes reduced to the consistency of a thick soup, usually of a grayish color. In this state it is called *chyme.*

The Chyme contains, after an ordinary meal, a considerable quantity of peptones, which are in part gradually absorbed into the blood and lymphatic vessels of the gastric mucous membrane and carried off, along with other dissolved and dialyzable bodies, e.g. salts and sugar. After the food has remained in the stomach some time (one and a half to two hours) the pyloric sphincter relaxes at intervals to allow the liquefied food to pass on in successive portions into the duodenum. At the end of three or four hours the stomach is ordinarily emptied, as the pyloric sphincter finally relaxes to such an extent as to allow even the large indigestible masses to be squeezed into the intestines.*

The Chyle.—The pancreas commences to secrete as soon

* Several of the above facts were first observed on a Canadian trapper, Alexis St. Martin, who as a result of a gunshot wound had a permanent opening from the surface of the abdomen to the interior of the stomach.

as food enters the stomach; hence a quantity of its secretion is already accumulated in the intestine when the chyme enters. The gall-bladder is distended with bile, secreted since the last meal. The acid chyme stimulating the duodenal mucous membrane causes a reflex contraction of the muscular coat of the gall-bladder, and a gush of bile is poured out into the chyme. From this time on both liver aud pancreas continue secreting actively for some hours, and pour their products into the intestine. The glands of the intestine are also set at work. All of these secretions are alkaline, and they suffice very soon to more than neutralize the acidity of the gastric juice, and so to convert the acid *chyme* into alkaline *chyle*. This, as found in the intestine after an ordinary meal, contains water, partly swallowed and partly derived from the salivary and other secretions, undigested proteids, some unchanged starch, oils from the fats eaten, peptones formed in the stomach but not yet absorbed, salines and sugar, which have also escaped complete absorption in the stomach, indigestible substances taken with the food, together with the secretions of the alimentary canal.

The Pancreatic Secretion is clear, watery, alkaline, and much like saliva in appearance. The Germans call the pancreas the "abdominal salivary gland." In digestive properties, however, the pancreatic secretion is far more important than the saliva, acting not only on starch but on proteids and fats. On starch it acts like the saliva, but more energetically because of the presence of the ferment amylopsin. It produces changes in proteids similar to those effected in the stomach, but by the agency of the ferment, *trypsin*, which differs from pepsin in being able to act in an alkaline, neutral or slightly acid solution. Upon fats the pancreatic juice has a complex effect. Through the action of another fer-

ment, *steapsin*, it splits up a portion of the fats into fatty acids and glycerin. The alkali present unites with the fatty acids to form soap in sufficient quantity to assist in emulsifying such portion of the fats as has not been split up. This process of changing fats into soaps is known as *saponification.* As soap and glycerin are soluble in water they are capable of absorption.* The greater part of the fats is not, however, so broken up, but merely mechanically separated into droplets which remain suspended in the chyle and give it a whitish color, just as cream particles are suspended in milk, or olive oil in mayonnaise sauce. If oil is shaken up with water, the two will not mix, but if some raw egg is added a creamy mixture is readily formed in which the oil remains for a long time evenly suspended in the watery menstruum. The reason of this is that each oil droplet becomes surrounded by a delicate pellicle of albumen and is thus prevented from fusing with its neighbors to make large drops which would soon float to the top. Such a mixture is called an *emulsion*, and the albumen of the pancreatic secretion emulsifies the oils in the chyle, making it white because the innumerable tiny oil-drops floating in it reflect all the light which falls on its surface. It is probable that fats in this condition of fine division may be absorbed without further change.

The saponification of fat, like the peptonizing of proteids, is but a step in the process of getting the fat into the blood. Fat alone is found in the blood; hence the soap formed is

$$^{*}\left.\begin{matrix}(C_{18}H_{35}O)_3\\ C_3H_5\end{matrix}\right\}O_3 + 3H_2O = 3\left(\left.\begin{matrix}C_{18}H_{35}O\\ H\end{matrix}\right\}O\right) + \left.\begin{matrix}C_3H_5\\ H_3\end{matrix}\right\}O_3$$

1 Stearin + 3 Water = 3 Stearic acid + 1 Glycerin.

Ordinary soap is a compound of a fatty acid with soda, colored and scented by the addition of various substances. Soft soap is a compound of a fatty acid with potash. Both dissolve in water, though the fats from which they are made will not.

undoubtedly reconverted into fat by the union of the fatty acids and glycerin.

The Bile.—Human bile when quite fresh is an alkaline golden-brown liquid. It contains coloring matters derived from broken down red blood corpuscles, mineral salts, water, and the sodium salts of two nitrogenized acids, *taurocholic* and *glycocholic*, of which the former predominates.

The Uses of Bile.—Bile has no digestive action upon starch or proteids and does not break up fats. Whether it emulsifies fats has been a matter of much discussion. It has been found by experimentation that if a rabbit is killed after having been fed with oil, no milky chyle is found above the point where the pancreatic duct opens into the intestine, although the bile entered and mixed with the intestinal contents a foot above this opening. The bile alone does not, therefore, emulsify fats in the rabbit. In many animals, as in man, the bile and pancreatic ducts open together into the duodenum, so that if an animal is killed during digestion and emulsified fats are found in the chyle, it is impossible to say whether or not the bile had a share in the process of emulsification. As, however, the bile of rabbits is much the same as that of other animals, it has been inferred that the bile does not emulsify fats in the intestine. Some have even gone so far as to say that the inertness of bile with respect to other foodstuffs makes it probable that it has no digestive power at all, but is merely an excretion which is passed out of the body through the alimentary canal.

There are many facts, however, which militate against this view. The bile enters the upper end of the small intestine at a point which necessitates its traversing more than twenty feet before it can pass from the body. Moreover, a large part of the bile is reabsorbed from the intestinal tract, to be

again secreted by the liver and again reabsorbed. Thus there is a strong supposition in favor of its being intended for special use in the intestinal tract. By its alkalinity it undoubtedly assists in overcoming the acidity of the chyme and so allows the pancreatic secretion to act more strongly. It probably helps to excite the contractions of the muscular coats of the intestines, since constipation often results when the bile duct is temporarily clogged, as it usually is in jaundice. It probably also acts as a preservative, for a deficiency of bile secretion is said to lead to putrefaction of the intestinal contents.

There are other facts, moreover, that point to the direct influence of the bile in promoting the absorption of fats. If one end of a very narrow glass tube is moistened with water, oil will rise in it but slightly; if the tube is moistened with bile instead of water, the oil will ascend higher. Again, oil passes through a membrane kept moist with bile under a much lower pressure than through one wet with water. Hence, it is quite possible that bile, by moistening the cells lining the intestines, may facilitate the passage of oily substances into the villi and thus promote the absorption of fats.

Moreover, experiment has shown that if the bile is prevented from entering the intestine of a dog he eats much more food than before, and that a great proportion of the fatty part passes out of the alimentary canal unabsorbed. There is no doubt, therefore, that the bile somehow aids in the absorption of fats.

The Intestinal Juice consists of the mixed secretions of the crypts of Lieberkühn and other glands of the intestine. It is very difficult to obtain it pure, and hence its digestive action is imperfectly known. It is alkaline and helps to over-

come the acidity of the chyme and to allow the trypsin of the pancreas to act on proteids. It seems capable itself of dissolving some kinds of proteids and turning them into peptones.

Intestinal Digestion.—Having considered separately the digestive actions of the different secretions poured into the small intestine, we may now consider their combined action. The acid chyme entering the duodenum from the stomach is more than neutralized by the alkaline secretions which it meets in the small intestine; it is made alkaline. This alkalinity allows the pancreatic secretion to finish the solution and transformation of proteids into peptones. The pancreatic secretion also continues the conversion of starch into maltose. The bile and pancreatic secretion are thoroughly mixed with the fats by the contractions of the intestine, producing an emulsion, which is taken up by the cells lining the intestine. To a certain extent the fats are also saponified. The result of all these processes is a thin, milky alkaline liquid called *chyle*.

Indigestible Substances.—With every meal several things are eaten which are not digestible. Among them are *elastic tissue*, forming a part of the connective tissue of all animal foods, and *cellulose*, the chief constituent of the cell walls in plants. The mucus secreted by the membrane lining the alimentary tract also contains an indigestible substance, *mucin*. These three materials, together with water, undigested foodstuffs, the coloring matter of bile, and other excretory substances found in the various secretions poured into the alimentary canal, form a residue which collects in the lower end of the large intestine, and is from time to time expelled from the rectum.

The regular daily expulsion of waste matters is of the ut-

most importance from the standpoint of health. If the food contains too little indigestible material there is not sufficient bulk remaining in the large intestine to insure its being moved forward by peristaltic action to the rectum for expulsion. The waste matters of some foods, as the bran of wheat, the fine beard of oats, by their irritation of the intestinal wall lead to a more vigorous peristalsis. Infrequent evacuation permits decomposition through the activity of the hordes of bacteria which infest the large intestine. To the absorption of the products of decomposition from the intestine are to be attributed some of the harmful effects of this condition. This is so common a trouble that it is not surprising that patent medicines owe their success to the fact that they are chiefly laxative and thus give temporary relief. Exercise, regularity of habit, the use of foods with a large share of waste, such as bread made of graham flour, onions, corn, green peas, fruits, and the drinking of plenty of water, are the best preventatives.

Dyspepsia is the common name of a variety of diseased conditions attended with loss of appetite or troublesome digestion. The immediate cause of the symptoms and the treatment necessary may vary widely; the detection of the cause and the choice of the proper remedial agents often call for more than ordinary medical skill. A few of the more common forms of dyspepsia may be mentioned here, with their proximate causes, not in order to enable people to undertake the rash experiment of dosing themselves, but to show how wide a chance there is for any unskilled treatment to miss its end and do more harm than good.

Appetite is primarily due to a condition of the mucous membrane of the stomach, which in health comes on after a short fast and stimulates its sensory nerves; loss of appetite

may be due to any of several causes. The stomach may be apathetic and lack its normal sensibility so that the empty condition does not act as a sufficient excitant. If food is taken at such a time it is often a sufficient stimulus, and "appetite comes with eating." A bitter solution before a meal is useful as an appetizer to patients of this sort. On the other hand, the stomach may be too sensitive, and a voracious appetite be replaced by nausea, or even vomiting, as soon as a few mouthfuls have been swallowed; the extra stimulus of the food overstimulates the too irritable stomach, just as a draught of mustard and warm water overstimulates a healthy one. The proper treatment in such cases should be soothing.* In states of general debility, when the stomach is too feeble to secrete under any stimulation, the administration of weak acids and artificially prepared pepsin is needed to supply gastric juice until the improved digestion enables the stomach to do its own work.

Enough has probably been said to show that dyspepsia is not a disease, but a symptom accompanying many diseased conditions, which require special knowledge for their treatment. Since it deprives the body of its proper nourishment, it tends to intensify itself and should never be neglected.

Absorption from the Alimentary Canal.—Through its whole extent the mucous membrane lining the digestive tube

* When food is taken it ought to stimulate the sensory gastric nerves, so as to excite the reflex centres for the secretory nerves and for the dilatation of the blood vessels of the organ; if it does not, the gastric juice will be imperfectly secreted. In such cases one may stimulate the secretory nerves by weak alkalies (p. 133), as apollinaris water or a little carbonate of soda, before meals; or give drugs, as strychnine, which increase the irritability of reflex nerve centres. The vascular dilatation may be helped by warm drinks, and this is probably the *rationale* of the glass of hot water after eating which has been in vogue.

is traversed by a very close meshwork of blood and lymph vessels. Matters ready for absorption pass through or between the cells covering the surface of the mucous membrane and then through the very thin walls of the smallest blood and lymph vessels; by these they are conveyed to the larger channels leading to the heart. From the heart the digested and absorbed food is distributed to every part of the body.

Absorption from the Mouth, Pharynx, and Gullet is ordinarily slight. Water, common salt, sugar and grape sugar are no doubt taken up during the processes of chewing and swallowing, but the time which elapses between taking a mouthful of food and its transference to the stomach is usually too short to allow any considerable absorption.

Absorption from the Stomach.—Food stays in the stomach a considerable time, and it might be supposed that absorbable material would be taken up to a considerable extent by the mucous membrane of the stomach and passed on into the general blood current. As a matter of fact, experiments have demonstrated very little absorption in this way.

Absorption from the Small Intestine is by far the most important in bringing nutritive matters into the body. The stomach is an organ rather of digestion than absorption; the small intestine, on the other hand, is specially constructed to absorb. Its valvulæ conniventes delay the progress of the food mass, while its innumerable villi, with their blood vessels and lymphatics (p. 125), reach out, like so many rootlets, into the chyle to take it up.

The sugars reaching the small intestine or formed in it are absorbed mainly into the blood and carried to the liver, where they are turned into *glycogen* for storage. The peptones passed into the intestine from the stomach, or formed in it by the action of the pancreatic secretion, are taken up

both by the lymphatics and by the blood vessels. The emulsified fats pass into the lymphatics of the villi and are carried by them to the blood.

The Lacteals.—The innumerable tiny fat drops drained off by the intestinal lymphatics or *lacteals* after an ordinary meal make their contents look white and milky, hence the name.* During fasting the lymphatics of the small intestine, like those in other parts of the body (see Chap. XIII.) convey a clear colorless liquid.

Dialysis.—When two specimens of water containing different matters in solution are separated from one another by a moist animal membrane, an interchange of material will take place under certain conditions. If a solution of common salt is placed in an apparatus (Fig. 66) on one side (B) of an animal membrane, and a solution of sugar in water on the other side (C), it will be found after a time that some salt has got into C and some sugar into B, although there are no visible pores in the partition, and the pressure of the liquid is the same on both sides. Such an interchange is said to be due to *dialysis* or *osmosis*, and if the process is allowed to go on for some hours the same proportions of salt and sugar will be found in the solutions on each side of the dividing membrane.

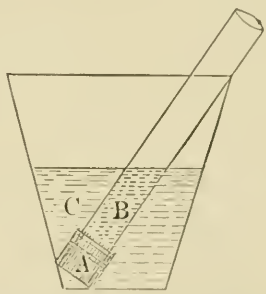

Fig. 66.—Dialyzing apparatus. *A*, animal membrane on end of tube separating two fluids; *B*, salt in tube; *C*, sugar in glass.

Substances differ much in the rapidity with which they may be dialyzed. Salts of various kinds ordinarily dialyze much more rapidly than sugar, peptone, etc. Many substances are incapable of dialyzation. Food materials are almost universally found among these, and hence there is the necessity

* From Latin *lac*, milk.

for digestion, which, by making the foods dialyzable, facilitates their absorption. Substances which are dialyzable are called *crystalloids*, those which are not, *colloids*.

Absorption from the Large Intestine.—In the duodenum the bulk of food entering from the stomach is increased by the bile and pancreatic secretions. Thenceforth absorption overbalances secretion, and the food mass becomes less and less in bulk to the lower end of the ileum. The contractions of the small intestine push forward its continually diminishing contents, until they reach the ileo-cæcal valve, through which they are ultimately pressed. When the mass enters the large intestine its nutritive portions have been almost entirely absorbed, and it consists chiefly of water, with the indigestible portions of the food and the secretions of the alimentary canal. It contains cellulose, elastic tissue, mucus, altered bile pigments, fat if a large quantity has been eaten, and starch if raw vegetables have formed part of the diet.

In the large intestine there is a considerable absorption of water and of the unabsorbed products of digestion. It is probable that digestion may continue to some degree here. When artificially prepared foods are injected into the rectum in sufficient amounts, the absorption is rapid enough to sustain life for several weeks under favorable conditions. although no food is taken into the stomach.

Finally the residue is expelled from the body.

CHAPTER XIII.

BLOOD AND LYMPH.

Why We Need Blood.—Some very small animals of simple structure require no blood; every part catches its own food and gives off its own wastes to the air or water in which the creature lives. When, however, an animal is larger and made up of many organs, some of which are far away from the surface of its body, this is impossible; some organs are therefore set apart to catch food, and arrangements made to carry this food to the others. In our own bodies many parts lie far away from the stomach and intestines which receive, digest, and absorb our food, and from the lungs which take oxygen from the air; yet every part, bone and muscle, brain and nerve, skin and gland, needs a constant supply of these to keep it alive. The division of labor, in accordance with which some organs are especially set apart for the purpose of receiving substances from the outside world to minister to the growth and repair of the body and to furnish energy, necessitates an arrangement by which the matters received shall be distributed to other parts. The distribution is accomplished by *the blood*, which goes to every organ from the crown of the head to the sole of the foot. As it flows from part to part, the blood takes nourishment from the alimentary tract and oxygen from the lungs, and gives them out to the parts which need them.

The Removal of Wastes.—The rapidly flowing blood not only conveys a supply of nutritive material for all the organs, but is a sort of sewage stream that drains off their wastes (p. 86), and carries them to the excretory organs, by which they are removed from the body.

The blood is a middleman, trading between the receiving organs (lungs and alimentary canal) and the tissues of the body, and again between the tissues and the excretory organs. Each part is thus kept supplied with food and freed from wastes, though it may lie far distant from all places where new materials first enter the body, and from those where refuse and deleterious substances are finally passed from it.

The Blood, as every one knows, is a red liquid which is very widely distributed over the body, since it flows from any part of the surface when the skin is cut. There are, however, a few parts into which blood is not carried. The outer layer of the skin,* hairs and nails, the hard parts of the teeth and most cartilages contain no blood; these *non-vascular* tissues are nourished by liquid which soaks through the walls of blood vessels in neighboring parts.

The Histology of Blood.—Fresh blood is to the unassisted eye a red opaque liquid showing no sign of being made up of different parts; but when examined by a microscope it is seen to consist of a liquid, *the blood plasma*, which has floating in it countless multitudes of closely crowded and extremely minute solid bodies known as *blood corpuscles*. The plasma is colorless and watery-looking; the corpuscles are of two kinds, *red* and *colorless*. The red corpuscles are by far the most numerous and give the blood its color; they are so tiny and so

* The absence of blood in the superficial layer of the skin may be readily shown: take a fine needle threaded with silk; by taking shallow stitches a pattern can be easily embroidered on the palm or back of the hand without drawing a drop of blood.

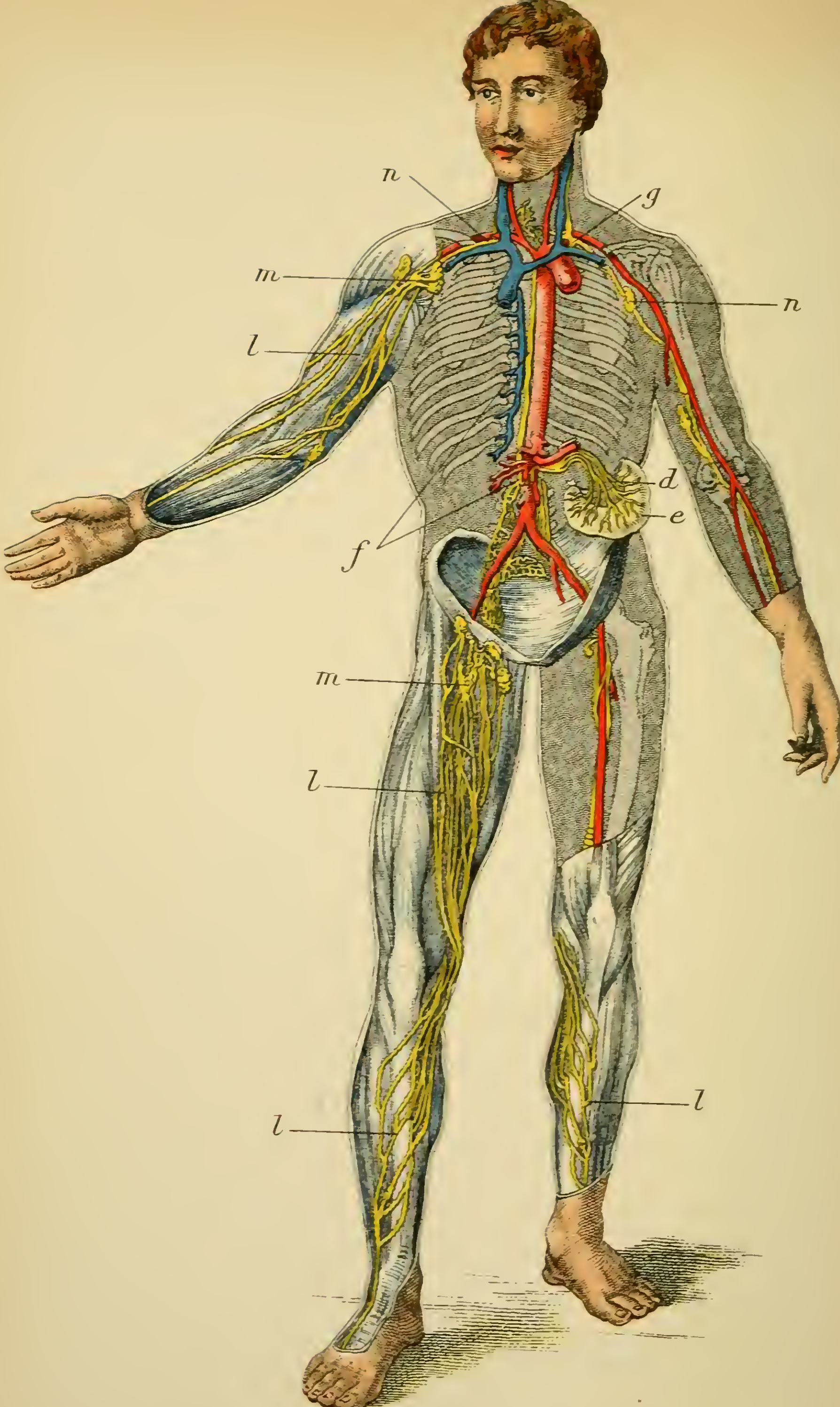

PLATE III.—A GENERAL VIEW OF THE LYMPHATICS OR ABSORBENTS. That portion of them known as the lacteals is seen at *d*, passing from the small intestine *e* to the thoracic duct *f*.

EXPLANATION OF PLATE III.

A General View of the Lymphatic or Absorbent System of Vessels.

At *e* is seen a portion of the small intestine from which lacteals or chyle-conveying vessels, *d*, proceed (their origin within the villi may be seen magnified in fig. 61); at *f* the *thoracic duct*, into which the lacteals open. This duct passes up the back of the chest, and opens into the great vein at *g*, on the left side of the neck: here the chyle mingles with the venous blood. In the right upper and lower limbs the superficial lymphatic vessels *l l l l*, which lie beneath the skin, are represented. In the left upper and lower limbs the deep lymphatic vessels which accompany the deep blood vessels are shown. The lymphatic vessels of the lower limbs join the thoracic duct at the spot where the lacteals open into it: those from the left upper limb and from the left side of the head and neck open into that duct at the root of the neck. The lymphatics from the right upper limb and from the right side of the head and neck join the great veins at *n*. At *m m* are seen the enlargements called lymphatic glands, situated in the course of the lymphatic vessels. These vessels convey a fluid called lymph, which mingles with the blood in the great veins. A fuller account of the lymphatic vessels in general, as distinguished from that section of them known as the lacteals, will be found on p. 159.

plentiful that about five millions of them are contained in a drop of blood the size of a small pinhead (1 cu. mm.). They are so closely packed that the unaided eye cannot see

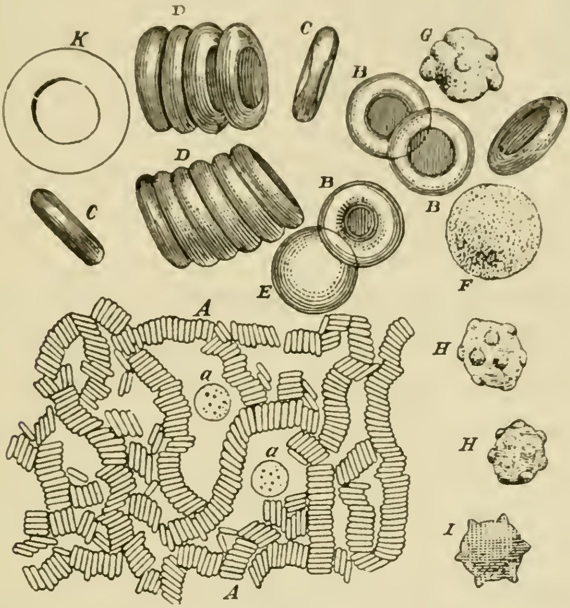

FIG. 67.—Blood corpuscles. *A*, magnified about 400 diameters. The red corpuscles have arranged themselves in rouleaux; *a*, *a*, colorless corpuscles; *B*, red corpuscles more magnified and seen in focus; *E*, a red corpuscle slightly out of focus. Near the right-hand top corner is a red corpuscle seen in three-quarter face, and at *C* one seen edgewise. *F*, *G*, *H*, *I*, white corpuscles highly magnified.

the spaces between them, and so the whole blood appears uniformly red.

Red Blood Corpuscles.—The red corpuscles of human blood (Fig. 67) are circular disks slightly hollowed out on each face. Seen singly with a microscope each is not red but pale yellow; a drop of blood spread out very thin on glass, or mixed with a tablespoonful of water, is also pale yellow; the corpuscles look red only when they are crowded together in a mass. Soon after blood is drawn most of the red corpuscles cohere side by side in rows, something like piles of coin.

The red corpuscles of most mammalia resemble those of man in being circular biconcave pale yellow disks; those of camels and dromedaries, however, are oval. The red blood corpuscles of birds, reptiles, amphibians, and fishes are oval and contain a nucleus in the centre such as is not found in human red corpuscles.

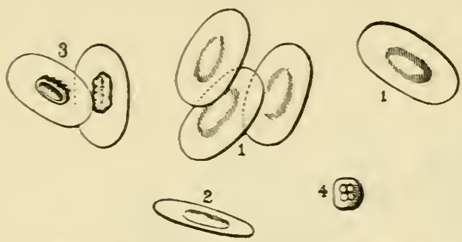

FIG. 68.—Red corpuscles of the frog.

The Origin of the Red Corpuscles.—In adult life the red blood corpuscles are constantly being destroyed and as constantly renewed. They are developed in the red marrow of the bones, thrown into the blood current to perform their work of carrying oxygen, and when apparently no longer able to do this work successfully, are destroyed by the liver.

Hæmoglobin.—Each red corpuscle is soft and jelly-like. Its chief constituent, besides water, is a proteid substance containing iron, *hæm'o-glo-bin,* which has the power of combining with oxygen when in a place where oxygen is plentiful, and of giving it off again in a region where it is present in small amount or not at all. This enables the blood to carry oxygen from the lungs to the active tissues which have used up their supply.

Hæmoglobin itself is dark purplish-red in color; hæmoglobin combined with oxygen is bright scarlet. Accordingly, the blood which flows to the lungs after giving up its oxygen is dark red, but becomes a bright scarlet after having received a fresh supply of oxygen from them.

The Colorless Blood Corpuscles are a little larger than the red, but much less numerous (about 1 to 300). As their

name implies, they contain no coloring matter. Each is a cell with a nucleus, and has the wonderful power of changing its shape. Watched with a microscope the corpuscles may be seen to alter their form slowly (Fig. 69), or even to creep across the glass. Their movements are very like those of the microscopic animal named *amœba*, and are accordingly called *amœboid*. These corpuscles are thus little, independently moving cells which live in the liquid of the blood. They apparently have the power of taking into their substance any foreign particles such as broken-down cells, bits of pigment which have been injected to test their voracity, and bacteria. These particles they digest by a chemical process not unlike in its results that which takes place in the alimentary tract of higher animals. They have the power of passing through the walls of the capillaries and of wandering about through the tissues of the body, literally "seeking what they may devour." Doubtless many disease-producing bacteria which have entered the body either through the lungs or by way of the mouth are successfully destroyed by the white blood corpuscles. This process is called *phagocytosis*.

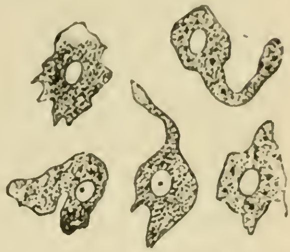

FIG. 69.—A white blood corpuscle, sketched at successive intervals of a few seconds to illustrate the changes of form due to its amœboid movements.

It is claimed by some that the main explanation of the body's resistance to many kinds of infection (invasion by bacteria) is found in the protection thus afforded by white blood corpuscles, and that the strength of the resistance is in proportion to the vigor of the corpuscles. When the bacterial invasion is too great to be handled successfully, the corpuscles are themselves destroyed by the bacteria. In abscesses we have usually a battleground of these two forces. The in-

vasion of the bacteria through a scratch or cut leads to irritation of the tissues; this in turn leads to the advance of the army of corpuscles. In the struggle many of the combatants on both sides are destroyed. Many times the corpuscles collect in such numbers that they fill up the tissues and even clog the circulation of the blood, thus shutting off food from themselves and the tissues and contributing to their own defeat. In the discharge (pus) from such abscesses, white blood corpuscles are found in immense numbers.

The Coagulation of Blood.—When blood is first drawn from the living body it is perfectly liquid, flowing as readily as water. This condition is only temporary; in a few minutes the blood becomes sticky and resembles a thick red syrup; the thickening becomes more and more marked, until, after the lapse of five or six minutes, the whole mass is a firm jelly and adheres to the vessel containing it, so that this may be inverted without spilling. This stage is known as that of *gelatinization*, and is also not permanent. In a few minutes the top of the jelly-like mass will be seen to be hollowed or "cupped," and in the concavity will be found a small quantity of nearly colorless liquid, the *blood serum*. The jelly next shrinks so as to pull itself loose from the sides and bottom of the vessel containing it, and as it shrinks it squeezes out more and more serum. Ultimately we get a solid *clot*, colored red and smaller in size than the vessel in which the blood coagulated, but retaining its form, and floating in a quantity of pale yellow *serum*. The whole series of changes leading to this result is known as the *coagulation* or *clotting* of the blood.

Cause of Coagulation.—If a drop of freshly drawn blood is studied under the microscope, one will observe beside the red and white blood corpuscles a colorless liquid in which they float. This is the *plasma* of the blood. Very fine solid

threads will be seen to separate out from the blood. These quickly run through the plasma in every direction and form a close network entangling the corpuscles. These threads are composed of an albuminous (proteid) substance known as *fibrin*. When they first form, the whole drop is much like a sponge soaked full of water (represented by the serum), and having solid bodies (the corpuscles) caught in its meshes. After the fibrin threads have been formed they begin to shorten; hence the fibrinous network tends to shrink in every direction, and this shrinkage is greater the longer the clotted blood is kept. At first the threads stick too firmly to the bottom and sides of the vessel to be pulled away, and thus the first sign of the contraction of the fibrin is seen in the cupping of the surface of the gelatinized blood where the threads have no solid attachment, and there the contracting mass presses out from its meshes the first drops of serum. Finally the contraction of the fibrin overcomes its adhesion to the vessel, and the clot pulls itself loose on all sides, pressing out more and more serum. The great majority of the red corpuscles are held back in the meshes of the fibrin.

The clotting of blood takes place only when blood is outside of the body, and is due to the action of a ferment (*fibrin-ferment*) upon one of the proteid substances dissolved in the plasma (*fibrinogen*). This coagulation of the blood resembles closely that of muscle, which is also caused by the action of a ferment. The total amount of fibrin formed is slight (0.2% of the weight of the blood).

Defibrinated or Whipped Blood.—As the essential point in coagulation is the formation of fibrin in the plasma, and as blood only forms a certain amount of fibrin,* if this is re-

* Fibrin is formed from *fibrinogen*, a soluble albumen existing in blood plasma.

moved as fast as it forms the remaining blood will not clot. The fibrin may be separated by what is known as "whipping" the blood. For this purpose freshly drawn blood is stirred vigorously with a bunch of twigs, to which the sticky fibrin threads adhere as they form. If the twigs are withdrawn a quantity of stringy material will be found attached to them. This is at first colored red by adhering blood corpuscles, but if washed in water pure white fibrin may be obtained in the form of highly elastic threads. The blood from which the fibrin has been removed looks like ordinary blood, but has lost its power of coagulating spontaneously.

Uses of Coagulation.—The living circulating blood in the healthy blood vessels does not clot, because it contains no solid fibrin, but this forms in it when the blood gets out of the heart or blood vessels, or when the lining of these is injured. In a wound, the clots close up the mouths of the small vessels which have been opened and stop the bleeding, which might otherwise go on indefinitely. So, too, when a surgeon ties an artery, the tight ligature crushes or tears its delicate inner surface, and causes the blood to clot there. The clot becomes more and more solid, and by the time the ligature is removed is organized into a firm plug which effectually closes the artery.

The Composition of Blood Serum.—About one half of the bulk of fresh blood is corpuscles and the other half plasma minus the constituents of fibrin. What the plasma contains we may learn by examining blood serum, which is plasma minus fibrinogen.

Blood serum is very different from water; if we keep on boiling pure water in a saucepan it will all go off in steam and leave nothing behind, but if we try to boil serum we find that we cannot do it; before it gets as hot as boiling water it sets

into a stiff, solid mass just like the white of a hard-boiled egg. In fact the serum contains dissolved in it two albumins very like that in the white of an egg, and coagulated in a similar way by boiling. About eight and a half pounds of albuminous substances exist in one hundred pounds of blood.

Blood serum also contains considerable quantities of oily and fatty matters, a little sugar, some common salt and carbonate of soda, and small quantities of very many other things, chiefly waste products from the various tissues. Nine tenths of the blood plasma is water.

Composition of the Red Corpuscles.—In the fresh moist state these contain a little more than half their weight of water. Nine tenths of their solid part is hæmoglobin, of which iron is one of the constituents; they also contain salts of phosphorus and of potassium.

The Blood Gases.—Ordinary fresh or salt water has a good deal of air dissolved in it; upon this fishes depend for their oxygen. Blood also contains a quantity of gases which it gives off when exposed to a vacuum, about sixty pints of gas to a hundred pints of blood. These gases are, chiefly, oxygen and carbon dioxide. In the lungs the carbon dioxide diffuses out from the plasma of the blood in which it is dissolved into the air contained in the air cells. From this air oxygen diffuses into the blood, to be taken up by the hæmoglobin of the red blood corpuscles. Hence the blood coming from the lungs is richer in oxygen and poorer in carbon dioxide. In the tissues which have only the carbon dioxide, this gas pushes its way into the blood, while the oxygen of the blood goes out to be used by the tissues; hence the blood returning to the heart is richer in carbon dioxide and poorer in oxygen.

The Blood as a Medium of Exchange.—"Blood, then, is a

very wonderful fluid: wonderful for being made up of colored corpuscles and colorless fluid, wonderful for its fibrin and power of clotting, wonderful for the many substances, for the proteids, for the ashes or minerals, for the rest of the things which are locked up in the corpuscles and in the serum.

"But you will not wonder at it when you come to see that the blood is the great circulating market of the body, in which all the things that are wanted by all parts, by the muscles, by the brain, by the skin, by the lungs, liver, and kidneys, are bought and sold. What the muscle wants it buys from the blood; what it has done with it sells back to the blood; and so with every other organ and part. As long as life lasts this buying and selling is forever going on, and this is why the blood is forever on the move, sweeping restlessly from place to place, bringing to each part the things it wants, and carrying away those with which it has done. When the blood ceases to move, the market is blocked, the buying and selling cease, and all the organs die, starved for the lack of the things which they want, choked by the abundance of things for which they have no longer any need."—*Foster*.

Hygienic Remarks.—The blood flowing from any organ will have lost or gained, or both gained and lost, when compared with the blood which entered it. But the losses and gains in particular parts of the body are in such small proportion, with the exception of the blood gases, as to elude analysis for the most part; moreover, since the blood from all parts is mixed up in the heart, they balance one another and produce a tolerably constant average. In health, however, the red corpuscles are present in greater proportion after a meal than before. Healthy sleep in proper amount also increases the proportion of red corpuscles, while want of it

diminishes their number, as may be recognized in the pallid aspect of a person who has lost several nights' rest. Fresh air favors their increase. *Anæmia* is a diseased condition characterized by pallor due to deficiency of red blood corpuscles, and accompanied by languor and listlessness. It is not unfrequent in young girls on the verge of womanhood, and in persons overworked and confined within doors. It must be remembered that the oxygen-carrying power of the blood is usually reduced in even greater proportion than the reduction in the number of red corpuscles would indicate. Since thereby the capacity for effort is correspondingly reduced, it is important for anæmic persons to take only moderate exercise. Fresh air and good food are the best remedies though medicines containing iron are often of great use.

The Quantity of Blood in the Body.—The total weight of the blood is about one thirteenth that of the whole body; a man of average size contains about twelve pounds of blood.

The Lymph.—The blood lies everywhere in closed tubes, and consequently does not come into direct contact with any of the body cells, except those which float in it and those which line the interior of the blood vessels. At two points in its course (*the capillaries of tissues and capillaries of lungs*), however, the vessels through which it passes have extremely thin walls, which permit the plasma to transude and bathe the various tissues. The transuded plasma is called *lymph*. It oozes through the walls of the capillaries into the spaces between the cells of the tissues and thus becomes the essential means of nourishing the cells of the body.

The lymph commonly contains all the elements of the body except the red blood corpuscles, though these elements are not found, upon analysis, to be in the same proportions as in the blood itself.

The Renewal of the Lymph.—The lymph present in any organ both gives to and receives from the cells; and so, although it may have originally been like the plasma of the blood, it soon acquires a different chemical composition. The cells take from it food materials to keep up their activity, and give to it the wastes resulting from such activity.

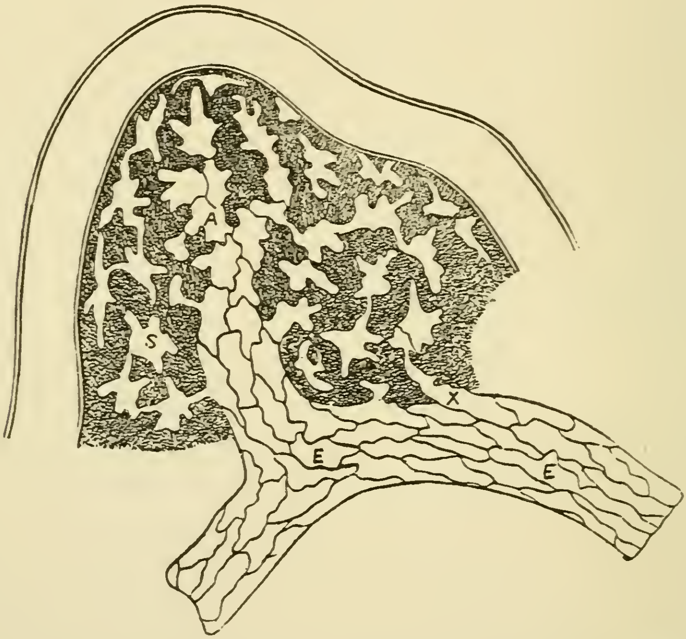

FIG. 70.—Origin of lymphatics (after Landois). *S*, lymph spaces communicating with lymphatic vessel; *A*, origin of lymphatic by union of lymph spaces; *E*, *E*, endothelial cells forming wall of lymph vessel.

Thus the lymph becomes progressively poorer in the essential constituents of the plasma and richer in waste matters. The lymph is constantly drained out of the intercellular spaces into the well-defined lymph channels, and slowly finds its way through successive bunches of lymph glands back into the blood. Fresh plasma constantly exudes from the capillaries to take the place of the lymph in the intercellular spaces and

to carry fresh food to the cells, again to be drained off through the lymphatic circulation. The exchanges of oxygen and carbon dioxide are chiefly by diffusion between the tissues and the blood, and do not depend upon the lymph.

The total amount of lymph passing back again into the blood circulation has been estimated to be equal to the total

FIG. 71.—Superficial lymphatics and glands. *G.* Axillary glands.

bulk of the blood, that is, one thirteenth of the weight of the body.

In consequence of the different wants and wastes of various cells, and of the same cells at different times, the lymph must vary considerably in composition in various organs of the body.

The Lymphatic Vessels or Absorbents.—The cells of the body, except the compact layers of epithelium composing surfaces, are rather loosely arranged in the various tissues and

organs. In the irregular branching spaces between the cells, the lymph which has exuded from the capillaries finds a

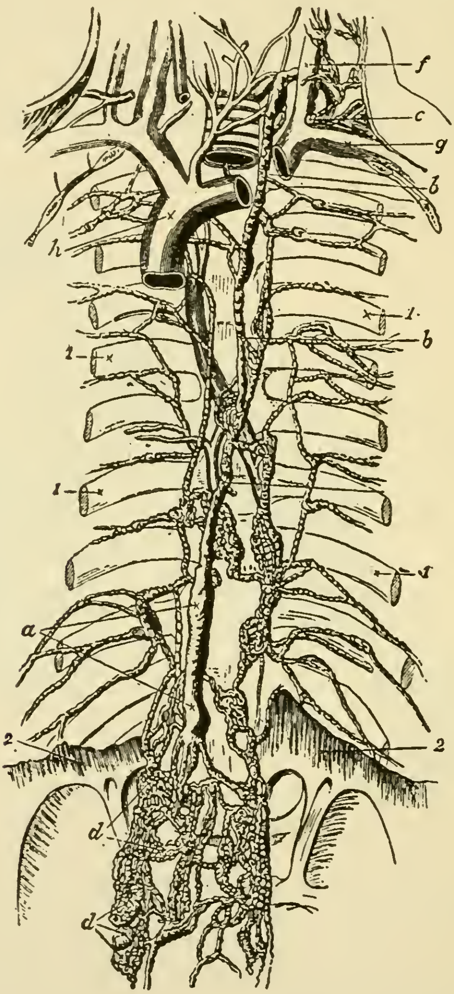

FIG. 72.—The lymphatic vessels. The thoracic duct occupies the middle of the figure. It lies upon the spinal column, at the sides of which are seen portions of the ribs (1). *a*, the receptacle of the chyle; *b*, the trunk of the thoracic duct, opening at *c* into the junction of the left jugular (*f*) and subclavian (*g*) veins as they unite into the left innominate vein, which has been cut across to show the thoracic duct running behind it; *d*, lymphatic glands placed in the lumbar regions; *h*, the superior vena cava formed by the junction of the right and left innominate veins.

temporary abiding place. Leading from these *lymph spaces* are delicate, thin-walled tubes, which join together to form

larger trunks. In the course of these trunks are situated knots or beads, called *lymph glands*, which are filled with cells resembling somewhat the white blood corpuscles. These glands are apparently for the purpose of supplying white corpuscles, and also of filtering the lymph and destroying, if possible, any foreign materials, such as bacteria, which may have been absorbed from the tissues. The lymph trunks join together to form still larger trunks which finally empty as single trunks, one upon each side of the neck, into the subclavian veins. The walls of the lymphatic tubes are exceedingly thin and the tubes themselves can only be readily found when they are distended with colored liquid. They are richly supplied with valves which allow the contents to flow only from the tissues toward the heart.

FIG. 73.—Valves of lymphatics. (Sappey.)

Since the lymphatic vessels take up or absorb the excess of liquid drained from the blood and also the effete matters of the various organs, they are frequently called the *absorbents*.

Lacteals, about which we have already learned, are the lymphatics of the small intestine (p. 125), but they are larger than the lymphatics of the rest of the system since the absorption into and circulation through them is much greater. The great lymphatic trunk which receives the lymph from the lower limbs and the food materials absorbed from the intestinal tract is called the *thoracic duct* and enters the left subclavian vein.

Histology of Lymph.—Pure lymph is a colorless, watery-looking liquid ; examined with a microscope it is seen to con-

tain numerous pale corpuscles exactly like the white blood corpuscles. These are derived in large part from the blood, but also from the glands through which the lymph comes.

Chemistry of Lymph.—Lymph is not quite so heavy as blood, though heavier than water. It may be described as blood *minus* its red corpuscles and considerably diluted, but of course in various parts of the body it contains minute quantities of substances derived from neighboring tissues.

Summary.—The lymph is a liquid in which the tissues of the body live; it is derived from the blood, and affords the immediate nourishment of the great majority of the living cells of the body; the excess of it is finally returned to the blood, which thus indirectly nourishes the cells by keeping up the stock of lymph. The lymph itself moves slowly, but is constantly renovated by the blood. The blood is kept in rapid movement by the heart, and besides containing a store of new food matters for the lymph, absorbs from it the gaseous waste products of the various cells.

CHAPTER XIV.

THE ANATOMY OF THE CIRCULATORY ORGANS.

The Organs of Circulation are the *heart* and the *blood vessels.* There are two distinct systems of blood vessels in the body, both connected with the heart; one system carries blood to, through, and from the lungs, and is known as the *pulmonary;* the other guides its flow through all the remaining organs, and is known as the *systemic.*

General Statement.—During life the pumping of the heart keeps the blood flowing rapidly through the blood vessels; these paths it never leaves except in cases of disease or injury.

The blood vessels form a continuous system of closed tubes comparable in a certain way to the water mains of a city; the heart corresponds to the reservoir, the great artery *(aorta)*, with its branches, to the main aqueduct and branch pipes. The course of the blood differs, however, essentially from that of the water supplied to a city, since the blood is carried back to the heart. There is at any instant only a small amount in the heart, but this is steadily replaced by an inflow as fast as it is forced out.

General Functions of the Parts of the Circulatory System.—The blood system is closed* except at two points, one

* In the spleen only is there a break in the continuity of the blood vessels. The blood escapes from the open ends of the blood vessels, flows through a meshwork of tissue cells, and re-enters the blood vessels at the end of a minute distance.

on each side of the neck, where lymph vessels pour the excess of lymph back into the veins. Valves at these two points let lymph flow into the blood vessels, but will not allow blood to flow out. Accordingly everything which leaves the blood must do so by oozing through the walls of the blood vessels, and everything which enters it must do the same, except matters conveyed in by the lymph at the points above mentioned. This interchange through the walls of the vessels takes place only in the capillaries. The capillaries, though far the smallest tubes in the vascular system, are the really important parts. The heart, arteries, and veins are merely arrangements for keeping the blood flowing through the capillaries. It is while flowing through these and soaking through their walls that the blood does its physiological work.

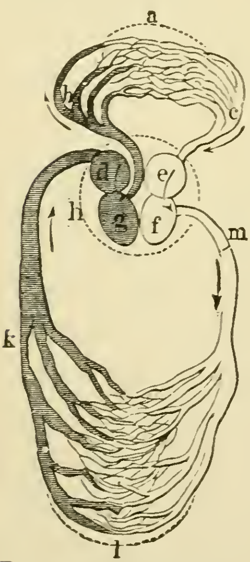

FIG. 74.—The heart and blood vessels diagrammatically represented.

Diagram of the Circulatory Organs.—The general relationship of the heart and blood vessels may be gathered from the accompanying diagram (Fig. 74). The heart is essentially a bag with muscular walls, internally divided into four chambers (*d*, *g*, *e*, *f*). The upper two (*d* and *e*) receive blood from vessels opening into them known as *veins*. Thence the blood passes on to the remaining chambers (*g* and *f*), which have very muscular walls, and, by forcibly contracting, drive the blood out into communicating vessels (*i* and *b*) known as *arteries*. The big arteries divide into smaller, these into still smaller (Plate IV), until the branches become too small to be traced by the unaided eye. The smallest branches are the *capillaries*, through which the blood

flows into the veins, which in turn convey it back to the heart. At certain points in the course of the veins valves are placed, to prevent a back flow. This alternating reception of blood at one end of the heart and its ejection from the other occurs in men about seventy times a minute during health.

The Position of the Heart.—The heart (*h*, Fig. 4) lies in the chest, immediately above the diaphragm and opposite the lower two thirds of the breast bone. It is conical in form and lies with its *base* or broader end turned upward and projecting a little to the right of the sternum. Its narrow end or *apex* may be felt beating between the cartilages of the fifth and sixth ribs to the left of the sternum. The position of the heart in the body is, therefore, oblique. It does not, however, lie on the left side, as is so commonly believed, but very nearly in the middle line, with the upper part inclined to the right, and the lower (which may be more easily felt beating—hence the common belief) to the left.

The Pericardium.—The heart is surrounded by a loose conical bag *(pericardium)* composed of connective tissue and attached by its broad lower part to the upper surface of the diaphragm. The pericardium is lined by a smooth *serous membrane* like that lining the abdominal cavity, which is continued over the heart itself and adheres closely to it. In the space between the pericardium and the heart is a small quantity of liquid which moistens the contiguous surfaces, and thereby diminishes the friction which would otherwise occur during the movements of the heart.

NOTE.—Sometimes, especially in rheumatic fever, the pericardium becomes inflamed *(pericarditis)*. In the earlier stages of this inflammation the rubbing surfaces on the outside of the heart and the inside of the pericardium become roughened, and their friction produces a sound which can be heard.

In later stages great quantities of liquid may accumulate in the pericardium and seriously impede the heart's beat.

The Cavities of the Heart.—On opening the heart (Fig. 74, p. 164) it is found to be divided into completely separate right and left halves by a longitudinal partition *(septum)* which runs from about the middle of the base to a point a little to the right of the apex. Each of the chambers on the sides of the septum is divided transversely into a thinner basal portion into which veins open *(auricle)* and a thicker apical portion from which arteries arise *(ventricle)*. The heart cavity thus consists of a right auricle and ventricle and a left auricle and ventricle, each auricle communicating with the ventricle on its own side by an *auriculo-ventricular orifice.* There is no direct communication through the septum between the opposite sides of the heart. To get from one side to the other the blood must leave the heart and pass through a set of capillaries, as may readily be seen by tracing the course of the vessels in Fig. 74.

The Vessels Connected with the Different Chambers of the Heart.—One big artery, called the *aorta*, springs from the left ventricle. It runs down to the pelvis, giving off many branches on its way, and then divides into two arteries, one going to each side, which by their branches supply pelvis and legs.

Its big branches divide into smaller and these into still smaller and spread through the whole body, to muscles, bones, skin, brain, stomach, intestines, liver, kidneys, etc., until they finally end in the systemic capillaries. The systemic veins collect the blood from the capillaries of the different organs, and unite to form the upper and lower hollow veins (the *superior* and *inferior venæ cavæ*). These carry the blood to the right auricle; thence it enters the right ventricle from

which arises one vessel, *the pulmonary artery*. The pulmonary artery divides into two branches, one for each lung; each branch splits up into minute arteries in its own lung, which end in the *pulmonary capillaries*. From the pulmonary capillaries the blood of each lung is collected into two *pulmonary veins*, which open into the left auricle.

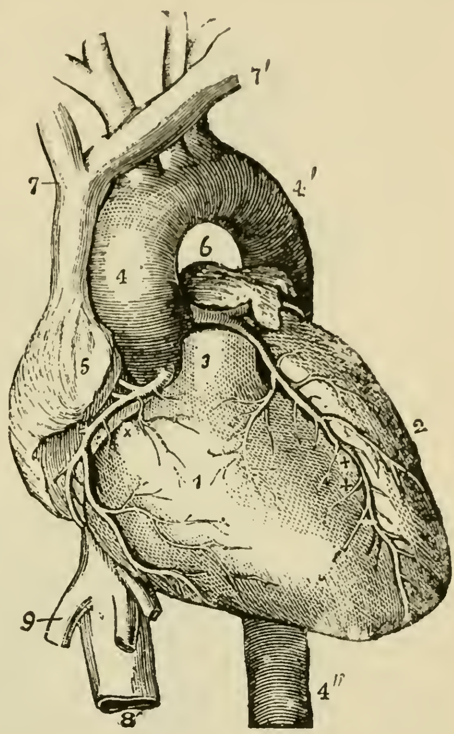

FIG. 75.—FRONT VIEW OF THE HEART AND GREAT VESSELS.

The pulmonary artery has been cut short close to its origin. 1, right ventricle; 2, left ventricle; 3, root of the pulmonary artery; 4, 4′, arch of the aorta; 4″, the descending thoracic aorta; 5, part of the right auricle; 6, part of the left auricle; 7, 7′, innominate veins joining to form the vena cava superior; 8, inferior vena cava; 9, one of the large hepatic veins; ×, placed in the right auriculo-ventricular groove, points to the right or posterior coronary artery; ×, ×, placed in the anterior interventricular groove, indicate the left or anterior coronary artery.

Summary.—One artery, the aorta, arises from the left ventricle. The blood carried out by the aorta passes through the capillaries in the tissues, returns by the upper and lower venæ cavæ to the right auricle, goes to the right ventricle, and thence through the pulmonary artery to the lungs. The blood, carried by the pulmonary artery from the right ventricle of the heart, passes through the capillaries of the lungs, returns to the left auricle by the pulmonary veins, enters the left ventricle, and begins its flow again through the aorta.

How the Heart is Nourished.—The heart is a hard working organ, and needs an abundant supply of nourishment; accord-

ingly its walls are permeated by a very close network of capillary blood vessels. The blood enters (Fig. 76) through

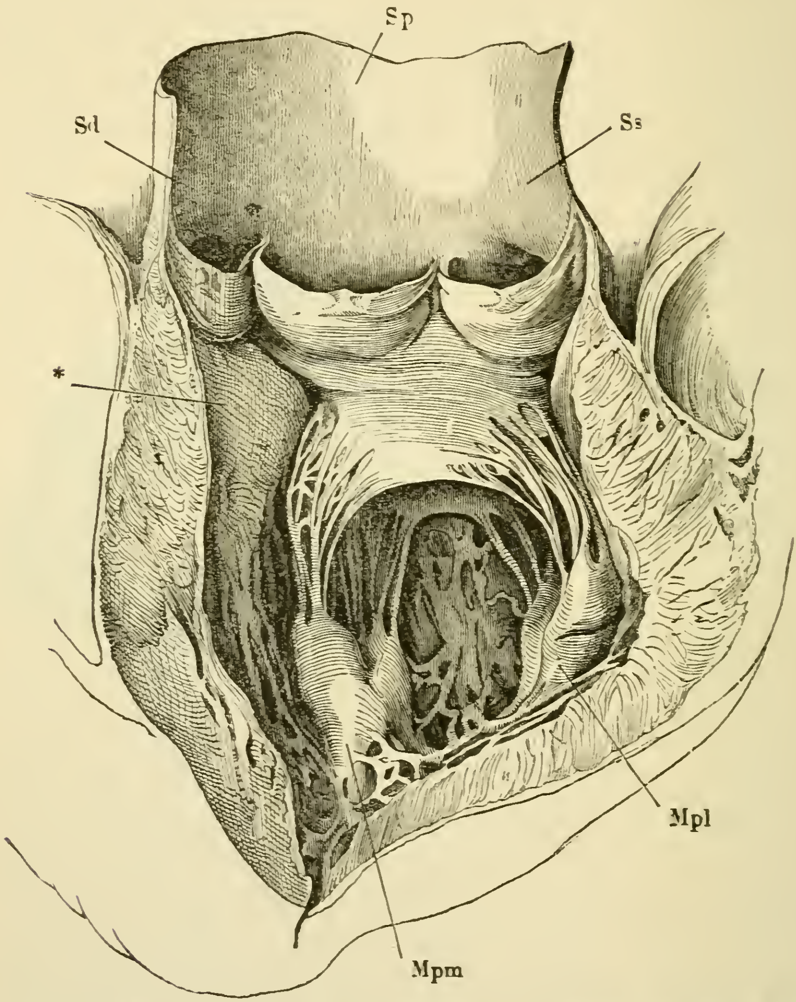

FIG. 76.—The left ventricle and the commencement of the aorta laid open. *Mpm*, *Mpl*, the papillary muscles. From their upper ends are seen the chordæ tendineæ proceeding to the edges of the flaps of the mitral valve. The opening into the auricle lies between these flaps. At the beginning of the aorta are seen its three pouch-like semilunar valves.

the right and left *coronary arteries* (the first two branches of the aorta) and leaves by the *coronary veins*, which carry it to the right auricle.

The Auriculo-Ventricular Valves.—Between each auricle of the heart and the ventricle of the same side are found valves which allow blood to pass from the auricle to the ventricle, but prevent any return. These valves are known as the *tricuspid* and *mitral* valves. The mitral valve (Fig. 76) consists of two flaps fixed by their bases to the margins of the opening between the left auricle and the left ventricle. Their unattached edges hang down into the ventricle when it is being filled and have fixed to them a number of stout connective-tissue cords, the *chordæ tendineæ*. These in turn are attached to muscular elevations, the *papillary muscles* (*Mpm* and *Mpl*) on the interior of the ventricle. The cords are long enough to let the valve flaps rise into a transverse position and thus to close the opening* between auricle and ventricle. The *tricuspid valve* is like the mitral, but with three flaps instead of two.

Semilunar Valves.—These are six in number, three at the mouth of the aorta (Fig. 76), and three at the mouth of the pulmonary artery. Each is a strong crescentic pouch fastened by its longer edge, with its free edge turned away from the heart. When the valves are closed, their free edges meet across the vessel and prevent blood from flowing back into the ventricle.

The Course of the Main Arteries of the Body (Fig. 77).—The aorta after leaving the left ventricle makes an arch (*a*A) with its convexity towards the head. From the beginning of this arch arise the *coronary arteries*, which carry blood into the walls of the heart. From the convexity of the arch spring three large arterial trunks, the *innominate*, the *left common carotid* (c*s*), and the *left subclavian* (s*si*). The

* This opening lies behind the opened aorta (*Sp*) and cannot be seen in the figure.

innominate artery soon divides into the *right subclavian* (*sd*) and the *right common carotid* (*cd*). Each common carotid runs up the neck on its own side and divides into branches for the neck, face, scalp and brain. Each subclavian gives off a branch, the *vertebral artery*, which passes to the brain through the transverse processes of the cervical vertebræ (Figs. 13 and 14, p. 25). The main branch of the subclavian continues across the arm pit as the *axillary artery* (A*x*) and then runs toward the elbow as the *brachial artery* (B). Just above the elbow it divides into the *radial* and *ulnar arteries* (R, U), which supply the fore-arm and end in small branches for the hand.

Beyond its arch the aorta runs close to the spinal column as the *thoracic aorta* (A*t*), which gives off branches to the walls and some of the organs of the chest. The vessel then passes through the diaphragm, and continues as the *abdominal aorta* (A*ab*) to the lower part of the abdomen. The main branches of the abdominal aorta are: (1) the *cœliac axis*, which divides into branches for the stomach, liver, and spleen: (2) the *upper* and *lower mesenteric arteries*, which supply the intestines with blood; (3) the *renal arteries* (K), which supply the kidneys.

The two trunks into which the posterior end of the abdominal aorta divides (*Ai*) are the *common iliac arteries*. Each gives off branches in the pelvis, and then continues along the thigh as the *femoral artery* (*C*): this runs to the knee joint, behind which it is called the *popliteal artery* (*Po*). The popliteal artery divides into the *peroneal* (*Pe*) and *tibial* (*Ta*, *Tp*) arteries, which supply the lower leg and the foot.

The Properties of the Arteries.—Two fundamental facts must be borne in mind in connection with the arteries: *first*, that they are highly elastic and extensible, much like a

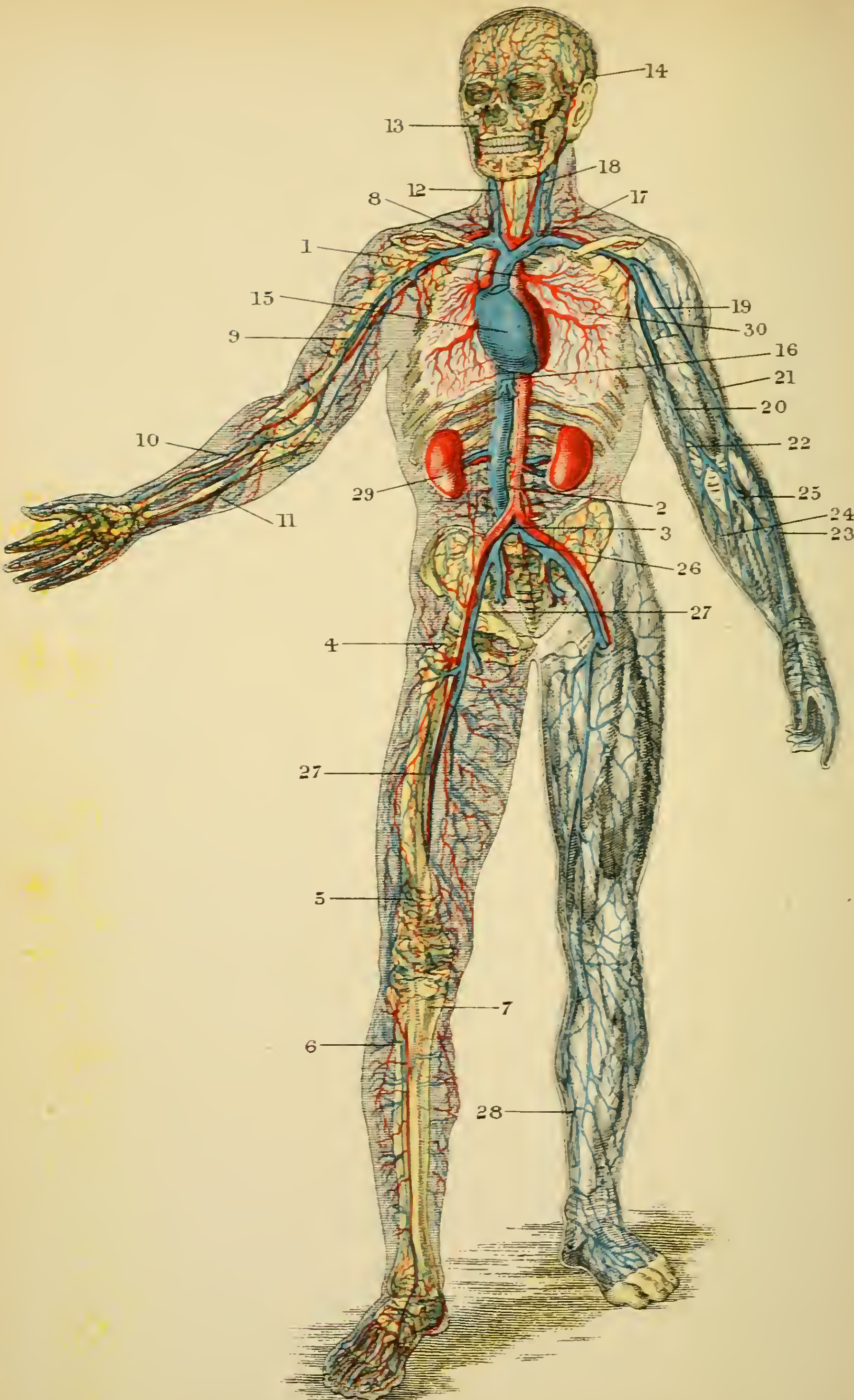

PLATE IV.—THE CHIEF ARTERIES AND VEINS OF THE BODY.

EXPLANATION OF PLATE IV

The Circulatory Organs.

The arteries (except the pulmonary) and the left side of the heart are colored red; the veins (except the pulmonary) and the right half of the heart blue. On the limbs of the left side the arteries are omitted and only the superficial veins are shown.

1. Aorta, near its origin from the left ventricle of the heart.
2. Lower end of aorta.
3. Iliac artery.
4. Femoral artery.
5. Popliteal artery ; the continuation of the femoral which passes behind the knee joint.

6, 7. The main trunks (anterior and posterior tibial arteries into which the popliteal divides).

8. Subclavian artery.
9. Brachial artery.
10. Radial artery.
11. Ulnar artery.
12. Common carotid artery.
13. Facial artery.
14. Temporal artery.
15. Right side of heart, with superior vena cava joining it above, and inferior vena cava (16) passing up to it from below.
17. Innominate vein, formed by the union of subclavian and jugular veins. The right and left innominate veins unite to form the superior cava.
18. Left internal jugular vein.
19. Axillary vein.
20. Basilic vein.
21. Cephalic vein.
22. Median vein.
23. Radial vein.
24. Ulnar vein.
25. Median vein.
26. Iliac vein.
27. Femoral vein.
28. Long saphenous vein.
29. The kidney ; attached to it are seen the renal artery and vein.
30. Branches of the pulmonary arteries and veins in the lung.

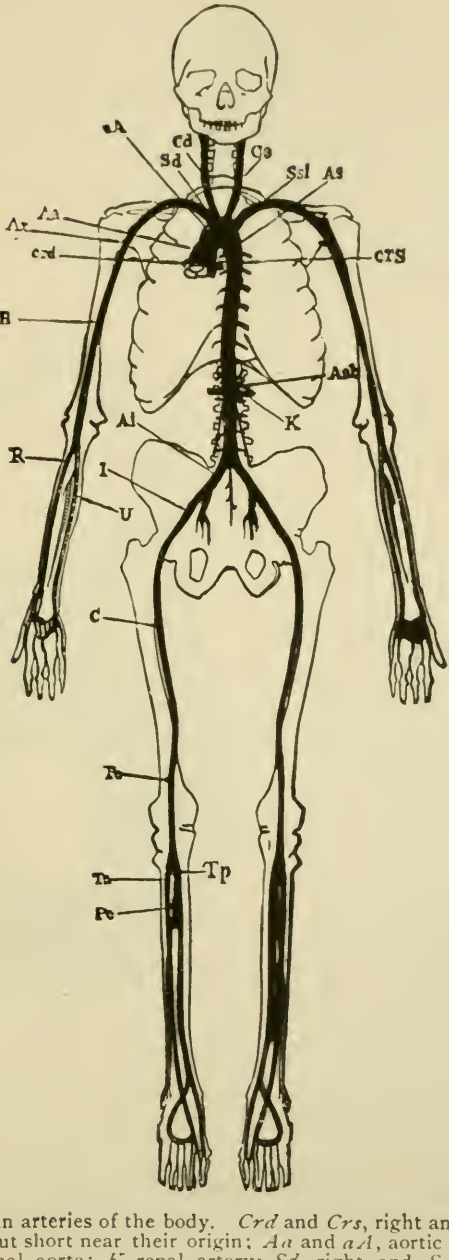

FIG. 77.—The main arteries of the body. *Crd* and *Crs*, right and left coronary arteries of the heart, cut short near their origin; *Aa* and *aA*, aortic arch; *At*, thoracic aorta; *Aab*, abdominal aorta; *K*, renal artery; *Sd*, right, and *Ssi*, left subclavian; *Cd*, right, and *Cs*, left carotid; *Ax*, axillary artery; *B*, brachial artery; *U*, ulnar artery; *R*, radial artery; *Ai*, common iliac artery; *I*, external iliac artery; *C*, femoral artery; *Po*, popliteal artery; *Ta*, anterior, and *Tp*, posterior tibial artery; *Pe*, peroneal artery.

piece of rubber tubing of the same size; *second*, that they have rings of muscular tissue in their walls. When these contract, the bore of the artery, and consequently the amount of blood which flows through it, is diminished. When they relax, the bore of the artery is increased, and more blood passes along it to the capillaries.

The Capillaries.—The smallest arteries (*arterioles*) pass

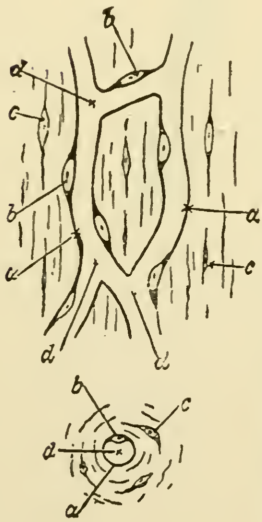

FIG. 78.

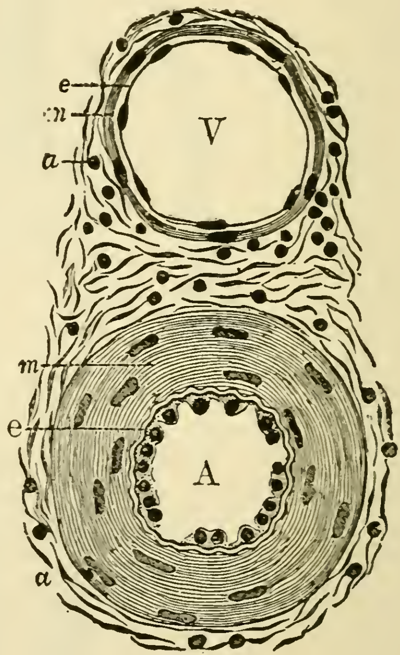

FIG. 79.

FIG. 78.—Diagrammatic representation of a capillary seen from above and in section. *a*, the wall of the capillary with. *b*, the nuclei; *c*, nuclei belonging to the connective tissue in which the capillary is supposed to be lying; *d*, the canal of the capillary.

FIG. 79.—Transverse section through a small artery and vein. *A*, artery; *V*, vein; *e*. epithelial lining; *m*, middle muscular and elastic coat. thick in the artery, much thinner in the vein; *a*, outer coat of areolar tissue (magnified 350 diameters).

into the *capillaries*, which have very thin walls, and form a close network in all parts of the body. The average diam-

eter of a capillary vessel is so small that only one or two blood corpuscles can pass through it abreast, and in many parts the capillaries lie so close together that a pin's point cannot be inserted between two of them, as, for example, in the deep layers of the skin, which cannot be pricked without drawing blood. Their immense number, however, much more than compensates for their size. It is while flowing in these delicate tubes that the blood does its nutritive work, for here only can the liquid containing nourishment exude from the blood through the thin walls to bathe the various tissues. Imagine a crumpled mass of the finest lace, with all its threads consisting of hollow tubes, and diminished twenty times in size, and you will have some idea of the size and richness of distribution of the capillaries.

The walls of the capillaries are formed of a single layer of flat cells and are really a continuation of the lining membrane of the arteries, veins, and heart, which thus becomes continuous throughout the circulatory system with the exception of the spleen.

The Veins.—The smallest veins arise from the capillary network and unite to form larger and larger trunks. One of these usually runs along with the main artery of the part, but there are ordinarily several other large veins just beneath the skin. This is especially the case in the limbs, the main veins of which are superficial, and can in many persons be seen as faint blue lines. The walls of the veins are similar in structure to those of the arteries, except that they are thinner.

Why the Large Arteries usually lie deep.—The heart pumps the blood with great force into the arteries, and when an artery is cut very rapid and dangerous bleeding occurs; the veins, if cut, do not bleed nearly so violently as an artery

of the same size. Hence it is less dangerous to have a large vein than a large artery close under the skin.

The Valves of the Veins.—Except the pulmonary artery and the aorta, which have the semilunar valves at their origin,

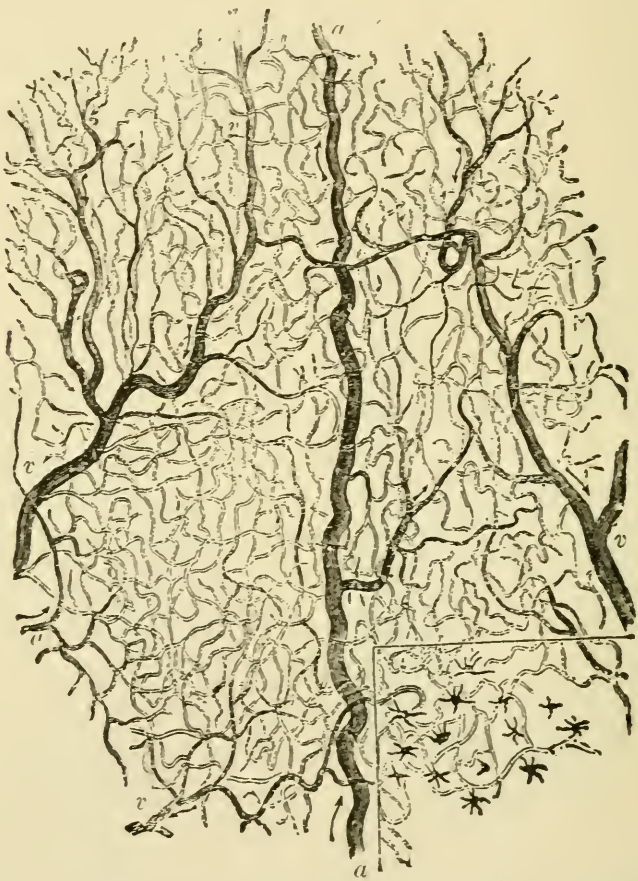

FIG. 80.—A small portion of the capillary network as seen in the frog's web when magnified about 25 diameters. *a*, a small artery feeding the capillaries; *v*, *v*, small veins carrying blood back from the latter.

arteries have no valves. Most veins, on the contrary, contain many valves formed by pouches of their lining, which resemble in form the semilunar valves of the aorta and the pulmonary artery. These valves permit blood to flow only

towards the heart, for a current in that direction (upper diagram, Fig. 82) presses the valve close against the side of

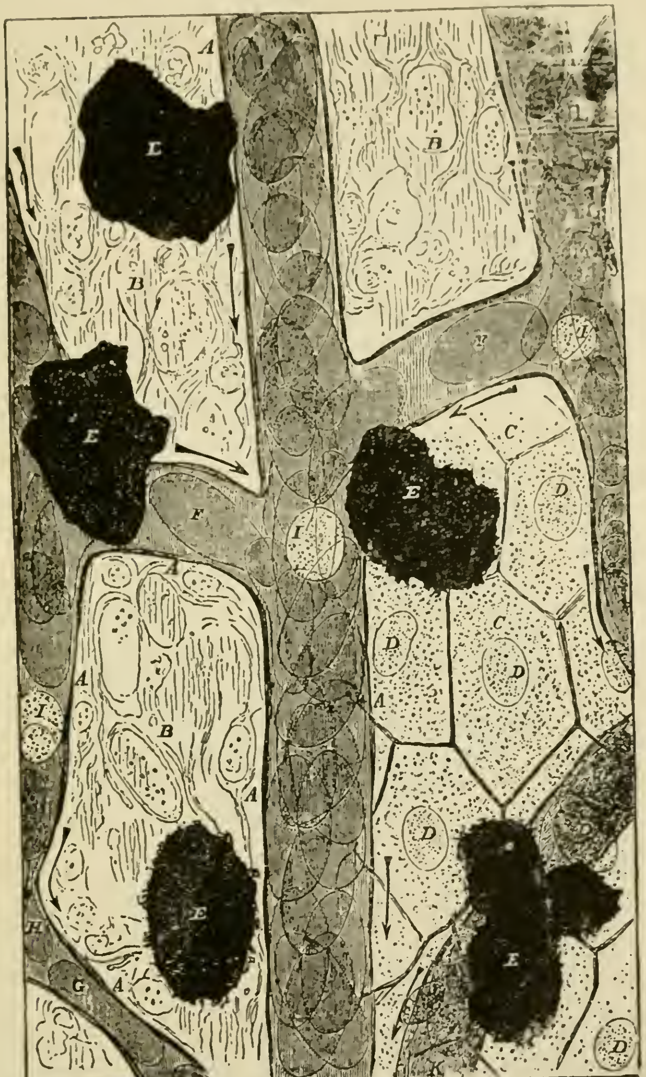

FIG. 81.—Circulation in frog's foot (under microscope). *A*, walls of capillaries; *B*, tissue of web lying between the capillaries; *C*, cells of epidermis covering web (these are only shown in the right-hand and lower part of the field; in the other parts of the field the focus of the microscope lies below the epidermis); *D*, nuclei of these epidermic cells; *E*, pigment cells contracted, not partially expanded; *F*, red blood corpuscle (oval in the frog) passing along capillary—nucleus not visible; *G*, another corpuscle squeezing its way through a capillary, the canal of which is smaller than its own transverse diameter; *H*, another bending as it slides round a corner; *K*, corpuscle in capillary seen through the epidermis; *I*, white blood corpuscle.

the vessel, and meets with no obstruction from it. Should any back flow be attempted, however, the current closes up the valve and bars its own passage (lower figure). These valves are most numerous in superficial veins and those of muscular parts. They are found especially where two veins join. Usually the vein is a little dilated opposite a valve, and hence in parts where the valves are numerous has a knotted look. On tying a cord tightly round the forearm, so as to stop the flow in its subcutaneous veins and cause their dilatation, the points at which valves are placed can be recognized by their swollen appearance.

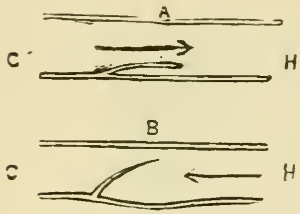

FIG. 82.—Diagram to illustrate the mode of action of the valves of the veins. *C*, the capillary; *H*, the heart end of the vessel.

The Course of the Blood.—From what has been said it is clear that the movement of the blood is a *circulation*. Starting from any one chamber of the heart it will in time return to it; but to do this it must pass through at least two sets of capillaries, one of which is connected with the aorta, and the other with the pulmonary artery. In this circuit the blood returns to the heart twice; leaving the left side it returns to the right, and leaving the right it returns to the left There is no road for it from one side of the heart to the other except through a capillary network. Moreover, it always leaves *from* a ventricle through an artery, and returns *to* an auricle through a vein.

There is then really only one circulation; but it is not uncommon to speak of the flow from the left side of the heart to the right through most of the body as the *systemic* or *greater circulation*, and of the flow from the right to the left through the lungs as the *pulmonary* or *lesser circulation*. But since, after completing either of these, the blood is not again

at the point from which it started, but is separated from it by the septum of the heart, neither is a "circulation" in the proper sense of the word, for a circulation implies that any object is at the end of its course where it was at the beginning.

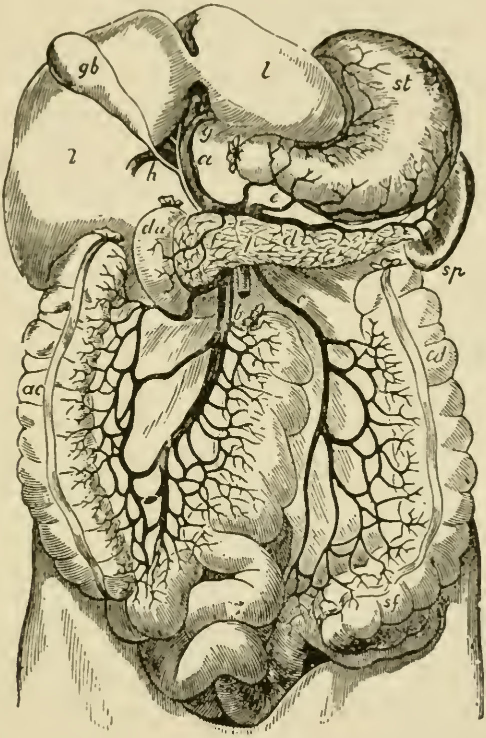

FIG. 83.—The portal vein and its branches. *l*, liver, under surface; *gb*, gall bladder; *st*, stomach; *sp*, spleen; *p*, pancreas; *du*, duodenum; *ac*, ascending colon; *cd*, descending colon; *a*. *b*, *c*, *d*, *e*, the portal vein and its branches. Portions of the duodenum and colon have been removed.

The Portal Circulation.—That portion of the blood which goes through the stomach and intestines has to pass through three sets of capillaries before it can return there. It leaves the left ventricle of the heart through the aorta, traverses the capillaries of the stomach and intestines, is carried by the *portal vein* into the liver, and here passes through the capillaries of the portal vein, which in the liver branches like an artery. From these it is collected by the *hepatic veins* and

poured into the inferior vena cava, which carries it to the right auricle, so that it has still to pass through the pulmonary capillaries to get back to the left side of the heart. The portal vein is the only one in the human body which thus like an artery feeds a capillary network. The flow from the stomach and intestines through the liver to the inferior vena cava is often spoken of as the *portal circulation.*

Diagram of the Circulation.—Since the two halves of the heart, although placed in proximity in the body, are completely separated from one another by an impervious partition, we may conveniently represent the course of the blood as in the accompanying diagram (Fig. 84), in which the right and left halves of the heart are represented at different points in the vascular system. Such a diagram makes it clear that the heart is really two pumps working side by side, each engaged in forcing blood to the other. Starting from the left auricle (*la*) we trace the flow through the left ventricle, along the branches of the aorta into the systemic capillaries (*sc*), thence through the systemic veins (*vc*) into the right auricle (*ra*), thence into the right ventricle (*rv*), through the pulmonary artery (*pa*) to the lung capillaries (*pc*) along the pulmonary veins (*pv*) to the left auricle, into the left ventricle (*lv*), and again into the aorta.

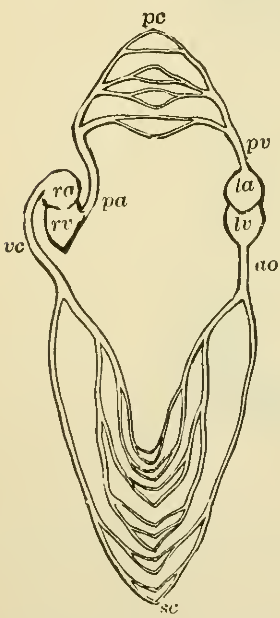

FIG. 84.—Diagram of the circulatory system, showing that it forms a single closed circuit with two pumps in it, represented by the right and left halves of the heart, which are separated in the diagram. *ra* and *rv*, right auricle and ventricle; *la* and *lv*, left auricle and ventricle; *ao*, aorta; *sc*, systemic capillaries; *vc*, venæ cavæ; *pa*, pulmonary artery; *pc*, pulmonary capillaries; *pv*, pulmonary veins.

Arterial and Venous Blood.—The blood when flowing in the pulmonary capillaries gives up carbon dioxide to the air, and receives oxygen from it. Since its coloring matter (hæmoglobin) forms a scarlet compound with oxygen (*oxy-hæmoglobin*), the blood which flows to the left auricle through the pulmonary veins is bright red. This color it maintains until it reaches the systemic capillaries, when it loses oxygen and becomes dark purple because of the excess of the darker colored hæmoglobin. In the lungs the hæmoglobin becomes again oxidized. The bright red blood, rich in oxygen and poor in carbon dioxide, is known as "arterial blood," and the dark red as "venous blood." It must be borne in mind that the terms apply to the character of the blood, and that the pulmonary *veins* contain *arterial* blood, and the pulmonary *arteries* contain *venous* blood. The change from arterial to venous takes place in the systemic capillaries, and from venous to arterial in the pulmonary capillaries.

Heart – [illegible] of [illegible]
Contraction [illegible]
Respiration in the lungs –

CHAPTER XV.

THE WORKING OF THE HEART AND BLOOD VESSELS.

The Beat of the Heart commences as a contraction of the mouths of the veins which open into the auricles. This contraction runs over the auricles, and is immediately taken up by the ventricles. The auricles relax the moment the ventricles start their contraction. Having finished their contraction, the ventricles begin to dilate, and then for some time neither they nor the auricles contract, but the whole heart expands. The contraction of any part of the heart is known as its *sys'to-le*, and the relaxation as its *di-as'to-le*. Since the two sides of the heart work synchronously, the auricles together and the ventricles together, we may describe a whole cardiac period or "heart beat" as made up successively of *auricular systole*, *ventricular systole*, and *pause*. In the *pause* the heart is soft and flabby, but during the systole it becomes hard and so diminished in size that the ventricles are entirely emptied.

The Cardiac Impulse.—The human heart lies with its apex touching the chest wall between the fifth and sixth ribs on the left side of the breast-bone. At every beat a sort of tap known as the cardiac impulse, or *apex beat*, may be felt by placing the finger at that point.

Events occurring within the Heart during a Cardiac Period.—Let us commence with the pause at the end of the ventricular systole. At this instant the semilunar valves in the orifices of the aorta and the pulmonary artery are closed so that no blood can flow back from these vessels. The whole heart, however, is soft and distensible, and readily yields to blood flowing into its auricles from the pulmonary veins and the venæ cavæ. This blood passes on through the open mitral and tricuspid valves, and fills up the dilating ventricles as well as the auricles. As the ventricles fill, the valve flaps float up so that by the end of the pause they are nearly closed. At this instant the auricles begin to contract at the mouths of the veins and narrow them; the relaxed ventricles oppose little resistance, and hence the auricles send most of the blood into the ventricles and but little back into the veins. When the auricles cease their contraction, the filled ventricles contract and by their pressure on the blood within, completely close the auriculo-ventricular valves. The blood in each ventricle is now imprisoned between the auriculo-ventricular valves behind and the semilunar valves in front. The former cannot yield on account of the chordæ tendineæ fixed to their edges; the semilunar valves, on the other hand, can open outward from the ventricle and let the blood pass on, but they are kept tightly shut by the pressure of the blood in the aorta and pulmonary artery. The contracting ventricle tightens its grip on the blood. As it squeezes harder and harder, its pressure on the blood becomes greater than the

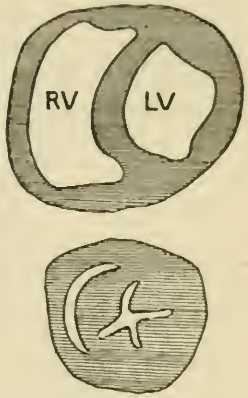

FIG. 85.— Transverse section through the middle of the ventricles of a dog's heart in diastole and in systole.

pressure exerted on the other side of the valves by the blood in the aorta, the valves are forced open, and the blood begins to pass out. The ventricle continues to contract until it has

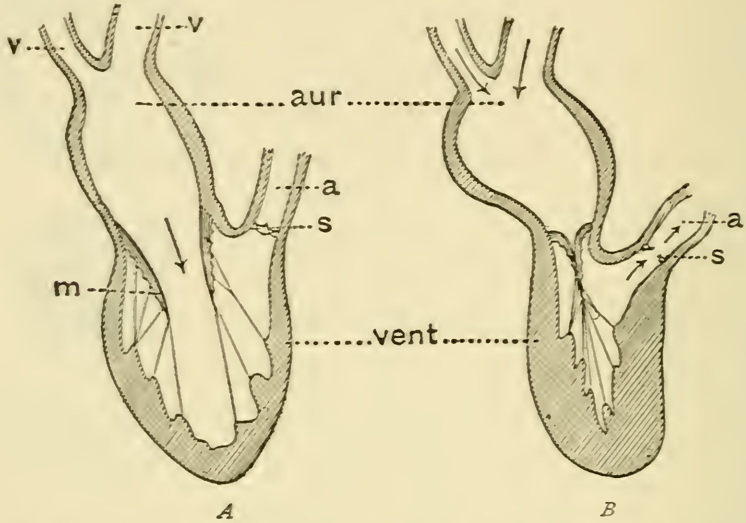

Fig. 56.—Diagram to illustrate the action of the heart. *aur.*, auricle; *vent.*, ventricle; *v*, veins; *a*, aorta; *m*, mitral valve; *s*, semilunar valves. In *A*, auricle contracting, ventricle dilated, mitral valve open, semilunar valves closed. In *B*, auricle dilated, ventricle contracting, mitral valve closed, semilunar valves open.

completely emptied itself, when it again commences to relax. Blood would now flow back into it from the arteries, were it not that this back current instantly catches the pockets of the semilunar valves, carries them back, and closes the valve so as to form an impassable barrier.

Use of the Papillary Muscles.—In order that the contracting ventricles may not force blood back into the auricles, it is essential that the flaps of the mitral and tricuspid valves be held together across the openings which they close, and not be carried back into the auricles. If they were like swinging doors and opened both ways they would be useless; they must so far resemble an ordinary door as only to open in one direction, namely, from the auricle to the ventricle. At the

commencement of the ventricular systole this is provided for by the chordæ tendineæ, which are of such a length and so arranged as to keep the valve flaps shut across the opening, and to maintain their edges in contact. But, as the contracting ventricles shorten, the chordæ tendineæ would be slackened and the valve flaps pushed up into the auricle, did not the little papillary muscles prevent this. By shortening as the ventricular systole proceeds, they keep the chordæ taut and the valves closed.

Sounds of the Heart.—If the ear is placed on the chest of another person over the heart region, two distinguishable sounds will be heard during each round of the heart's work. They are known respectively as the *first* and *second sounds* of the heart. The first is of lower pitch, lasts longer and is less sharp than the second. Vocally their character may be tolerably imitated by the syllables *lūb, dŭp*. The cause of the second sound is the closure of the semilunar valves. The first sound takes place during the ventricular systole, and is probably due to vibrations of the tense valve flaps and the ventricular wall. In many forms of heart disease these sounds are modified or cloaked by additional sounds due to the roughened, narrowed or dilated cardiac orifices, or to the inefficiency of the valves. A physician often gets important information as to the nature of a heart disease by studying these new or altered sounds.

Function of the Auricles.—The ventricles have to do the work of pumping the blood through the blood vessels. Accordingly their walls are far thicker and more muscular than those of the auricles; the left ventricle, which has to force the blood over most of the body, is stouter than the right, which has only to send blood around the comparatively short pulmonary circuit. The circulation of the blood is, in fact,

maintained by the ventricles, and one may be led to inquire what is the use of the auricles. During the pause of the heart the blood flows on through the auricles into the ventricles, which are already nearly full when the auricles contract; this contraction merely completes the filling of the ventricles. The main use of the auricles then is to afford a reservoir into which the veins may empty while the comparatively slow ventricular contraction is taking place.

The Work Done Daily by the Heart.—"The 'work done' by a contracting muscle is expressed by the *height* to which a weight is raised. In the case of the heart, the weight raised is the amount of blood contained in the ventricles; the height to which that weight would be raised is the height of intraventricular blood-pressure during systole. From these data it is easy to calculate the 'work' done at each systole, and knowing the pulse-frequency, the average per hour or per day is also known. Admitting for the left ventricle an average discharge of 120 grams, and a systolic pressure of 2 meters, the work done at each contraction will amount to 150 grammeters; to this amount we may add 50 grammeters as the work done by the right ventricle and by the two auricles, making up a total of 200 grammeters or $\frac{1}{5}$ kilogrammeter as the work done by the heart at each beat. With a pulse-frequency of 72 per minute this would amount to 864 kgm. per hour, or more than 20,000 kgm. per diem. The whole of this energy is expended in the body, partly in overcoming resistance in the vascular system, and partly transformed into and discharged as heat; in this form the contractions of the heart yield about $\frac{1}{50}$th of the total daily heat production."—*Waller.*

If a man weighing 165 pounds climbs a mountain 2500 feet high the muscles of his legs will be tired at the end of

his journey, and yet in lifting his body that height they have done only as much work as his heart does every day without fatigue in pumping his blood.

No doubt the fact that more than half of every round of the heart's activity is taken up by the pause during which its muscles are relaxed and its cavities filling with blood has a great deal to do with the patient and tireless manner in which it pumps along, minute after minute, hour after hour, and day after day, from birth to death.

During the pause between contractions, the heart muscle gets its rest ; it has been estimated that the heart muscle does active work during only eight hours of the twenty-four and rests during sixteen. When the heart beats more rapidly the period of contraction changes but little, the extra beats encroaching upon the resting time. In fever, when the heart beat is much more rapid, it has less time to rest and is liable to become exhausted by overwork with insufficient recuperation.

The Nerves of the Heart.—The beat of the heart is due to the contraction of the muscle fibres making up its wall. This contraction is caused by nervous impulses received from nerve centres, as will be explained later. These nerves (intrinsic heart nerves) are in close connection with the muscle fibres and tend to cause them to contract regularly and somewhat rapidly. Their influence is modified by a second set of nerves (*pneumogastric*, or *vagus*) which tend to make the heart beat more slowly, that is, to inhibit the action of the intrinsic nerves. A third set (*accelerator*) have apparently the power of quickening the heart's action. The rate and strength of the beat at any time is due to an involuntary balancing of the influences of the first two sets (and possibly the third) to meet the body's needs. The need of oxygen

has the chief influence in modifying the heart's beat, as will be seen under respiration.

The Pulse.—When the left ventricle of the heart contracts it forces on about 120 grams of blood into the aorta, which, with its branches, is already full of blood. The elastic arteries are consequently stretched by the extra blood. This dilatation of an artery following each beat of the heart is called *the pulse*. It is best felt on arteries which lie near the surface of the body, as *the radial artery*, near the wrist, and *the temporal artery*, on the brow.

Before the next heart beat occurs, the arteries by their elasticity have forced through the capillaries as much blood as the aorta received during the preceding ventricular systole; consequently they shrink again during the pause, just as a piece of rubber tubing with a small hole in it, when overfilled with water, gradually collapses as the water flows out of it. The next beat of the heart again overfills and expands the arteries, and so on. Thus at each heart beat there is a dilatation of the arteries due to the blood sent into them from the ventricle, and between each beat there is a partial emptying of the arteries, due to their forcing some of their contents into the capillaries.

What may be learnt from the Pulse.—Since the pulse is dependent on the heart's systole, "feeling the pulse" gives a convenient means of counting the rate of the heart beat. To the skilled touch, however, it tells much more; as, for example, a readily compressible or "soft pulse" shows that the heart is not keeping the arteries properly filled with blood; a tense and rigid or "hard pulse" indicates that the heart is keeping the arteries excessively filled, and is working too violently. In healthy adults the pulse rate varies from sixty-five to seventy-five a minute, the most common rate being seventy-

two. In the same individual it is faster when standing than when sitting, and when sitting than when lying down. Any exercise or excitement increases its rate temporarily. A sick person's pulse should not therefore be felt when he is nervous or excited. In children the pulse is quicker than in adults, and in old age slower than in middle life.

The Flow of the Blood in the Capillaries and Veins.—The movement of the blood from the heart is intermittent, coinciding with each systole of the ventricles. Before it reaches the capillaries, however, this rhythmic movement is transformed into a steady flow, as may readily be seen by examining with a microscope thin transparent parts of various animals, e.g. the web of a frog's foot, a bat's wing, or the tail of a small fish. In consequence of the steadiness with which the capillaries supply the veins the flow in them is also unaffected by the beat of the heart. If a vein is cut the blood wells out uniformly, whereas a cut artery spurts out in powerful jets which correspond with the contractions of the ventricles.

The Circulation of the Blood as Seen in the Frog's Web.—There is no more fascinating or instructive spectacle than the circulation of the blood in the thin membrane between the toes of a frog's hind limb as seen with the microscope. Upon focusing beneath the outer layer of the skin, a network of minute arteries, veins, and capillaries, with the blood flowing through them, comes into view (Figs. 84 and 86). The arteries are readily recognized by the fact that the flow in them is fastest and from larger to smaller branches. The smallest end in a capillary network, the channels of which are all nearly equal in size. In the veins arising from the capillaries the flow is from smaller to larger trunks, slower than in the arteries, but faster than in the capillaries.

The Blood flows most slowly in the Capillaries because

their united area is many times greater than that of the arteries supplying them, so that the same quantity of blood flowing through them in a given time has a wider channel to flow in. The aggregate area of the veins is smaller than that of the capillaries, but greater than that of the arteries; therefore the rate of movement in them is intermediate.

If the aggregate areas of all the branches of the circulatory system were taken, beginning at the origin of the aorta, we should have a double cone, as represented in Fig. 87. Starting at the beginning of the aorta we have a tube one inch in diameter, which gradually expands because of the increased

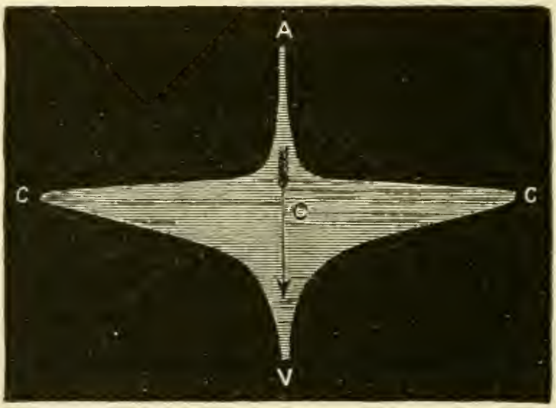

FIG. 87.—Diagram intended to give an idea of the aggregate sectional diameter of the different parts of the vascular system. *A*, arteries; *C*, capillaries; *V*, veins. (After Schofield.)

aggregate capacity of the arterial branches until the capillary region is reached. Here there is a sudden expansion to a tube approximately two feet in diameter. There is now a rapid and then a gradual reduction in size until the tube representing the venæ cavæ has a diameter of two inches. Just as water forced in at a narrow end of this tube would flow quickly there, slowly at the widest part, and more quickly again where it passed from the other narrow end, so the blood flows rapidly in the aorta and the venæ cavæ,* and slowly in

* A good illustration taken from physical geography is afforded by

the capillaries, which, though thousands of times smaller than the great arteries and veins, are millions of times more numerous.

Why there is no Pulse in the Capillaries and Veins.—The disappearance of the pulse in the arterioles has two causes, (1) the elasticity of the arteries and (2) the resistance offered to its flow by friction in the smaller vessels.

On account of this friction the larger arteries have difficulty in sending blood through them; it therefore accumulates in the aorta and its large branches and stretches their elastic walls. The stretched arteries press constantly on the blood within, and keep squeezing it through the arterioles into the capillaries, both during systole and diastole. The heart, in fact, keeps the big elastic arteries over-distended with blood, since before they have had time to lose their grip on the blood within, another systole occurs and fills them up tight again. As the arteries are thus always stretched and always pressing on the blood, the capillaries receive a steady supply and the flow through them is uniform. This even capillary flow passes on a steady blood stream to the veins.*

the Lake of Geneva, in Switzerland. This is supplied at one end by a river which derives its water from the melting glaciers of some of the Alps. From its other end the water is carried off by the river Rhone. In the comparatively narrow inflowing and outflowing rivers the current is rapid; in the wide bed of the lake it is much slower.

* "Every inch of the arterial system may, in fact, be considered as converting a small fraction of the heart's jerk into a steady pressure, and when all these fractions are summed up together in the total length of the arterial system no trace of the jerk is left. As the effect of each systole becomes diminished in the smaller vessels by the causes above mentioned, that of this constant pressure becomes more obvious, and gives rise to a steady passage of the fluid from the arteries towards the veins. In this way, in fact, the arteries perform the same functions as the air-reservoir of a fire-engine, which converts the jerking impulse given by the pumps into the steady flow of the delivery hose."—*Huxley*.

The Object of having no Pulse in the Capillaries is to diminish the danger of their rupture. As we have seen, liquid has to ooze through their walls to nourish the organs of the body, and wastes from the organs must get to the blood that they may be carried off. Their walls have therefore to be very thin, and if the blood were sent into them in sudden jets at each beat of the heart, they would run much risk of being torn.

The Muscles of the Arteries.—The arteries have rings of plain muscular fibre in their walls; when these contract they narrow the artery, and when they relax they allow it to widen under the pressure of the blood in its interior. The vessel then carries more blood to the capillaries of the organ which it supplies. *Blushing* is due to a relaxation of the muscular layer of the arteries of the face and neck, allowing more blood to flow to the skin.

Why the Arteries have Muscles.—The amount of blood in the body is not sufficient to allow a full stream of blood through all its organs at one time. The muscular fibres controlling the diameter of the arteries are used to regulate the blood flow in such a manner that parts hard at work shall get an abundant supply, and parts at rest shall get just enough to keep them nourished. Usually when one set of organs is at work and its arteries dilated, others are at rest and their arteries contracted: for example, when the brain is at work, its vessels are dilated and often the whole head flushed; when the muscles are exercised, a great portion of the blood of the body is carried off to them; during digestion, the vessels of the alimentary tract are dilated and absorb a large share of blood.

This control of the amount of blood which any organ receives is accomplished by nerve control through the branches

of the sympathetic system upon the muscle fibres in the walls of the arterioles. These branches are called *vaso-motor nerves* and the control is called vaso-motor action. Contraction of the arteriole walls is *vaso-constriction*, and relaxation of walls *vaso-dilatation*. Vaso-motor action makes it possible to give any organ the amount of blood it needs at any time without calling upon the heart for extra work.

We can therefore understand how hard thought or violent exercise soon after a meal, by diverting the blood from the abdominal organs, is apt to produce an attack of indigestion. Young persons whose organs have a superabundance of energy, which enables them to work under unfavorable conditions, are less apt to suffer in such ways than their elders. One sees boys running about after eating, when older people feel a desire to sit quiet or even to sleep.

Exposure to Cold.—Prolonged exposure of the surface to cold is very apt to be followed by a catarrhal condition of the mucous membranes of the nose, throat, lungs, or intestines (diarrhœa). Summer diarrhœa is more often due to a chill of the surface than to the fruits eaten. The best preventive is to wear, when exposed to sudden changes of temperature, a woollen garment* over the trunk of the body; cotton and linen permit any change in the external temperature to act almost at once upon the skin. After an unavoidable exposure to cold or wet, the thing to be done is of course to maintain the cutaneous circulation; movement should be persisted in,

* In tropical countries, it is customary for soldiers to wear a flannel band over the abdomen, in addition to other clothing, to prevent chill and consequent diarrhœa. This has come to be known as a cholera belt, since it has been credited with considerable influence in reducing the frequency of severe attacks of diarrhœa, which is one of the most easily recognized symptoms of cholera.

and a thick dry outer covering put on until warm and dry underclothing can be obtained.

In healthy persons, a temporary exposure to cold, as a plunge in a bath, is good, since in them the sudden contraction of the cutaneous arteries soon passes off, and is succeeded by a dilatation causing a warm healthy glow on the surface. If the bather remains too long in cold water, however, this reaction passes off and is succeeded by a more persistent chilliness of the surface, which may last all day. The bath should therefore be left before this occurs; but no absolute time can be stated, as the reaction is more marked and lasts longer in strong persons and in those used to cold bathing than in others.

It is undoubtedly true, however, that many persons who attempt to take daily cold baths fail to get a warm reaction and are physically depressed rather than stimulated. Others who have a tendency to neuralgia or rheumatism may have these conditions aggravated by such exposure to cold. It is much wiser for these persons to take tepid or warm baths.

CHAPTER XVI.

THE OBJECT AND THE MECHANICS OF RESPIRATION.

The Object of Respiration.—Blood is renewed, as far as food materials are concerned, by substances either directly absorbed by the blood vessels of the alimentary canal, or taken up by the lymphatics of the digestive tract and afterwards poured into the blood. In order that energy may be set free (Chap. VIII), oxidations must occur, necessitating a constant supply of oxygen. Waste substances are thus produced, which are no longer of use to the body, but detrimental to it if present in large quantity. The most abundant of these wastes is carbon dioxide gas.

The function of respiration has for its object (1) to renew the supply of oxygen in the blood, and (2) to get rid of the carbon dioxide produced in the different organs.

The Respiratory Apparatus consists primarily of two elastic bags, *the lungs*, placed in a cavity with extensible walls, the *thorax*. They are filled with air and communicate by *air passages* with the surrounding atmosphere. In the walls of the lungs the capillary blood vessels form a very close network. Through their walls the blood receives oxygen from the air and gives in return carbon dioxide. The air in the lungs consequently needs renewal, since otherwise it would soon have no oxygen to give to the blood, and would become

so loaded with carbon dioxide that it could no longer receive it from the blood. This renewal is effected by a system of muscles, bones, and cartilages which co-operate to bring about that alternating expansion and contraction of the chest which we call *breathing*. When the chest contracts, air poorer in oxygen and richer in carbon dioxide is expelled from the lungs; when it expands, fresh air, rich in oxygen, and containing hardly any carbon dioxide, is taken into them.

The respiratory organs are (1) the lungs; (2) the air passages; (3) the vessels of the pulmonary circulation, including the pulmonary artery bringing the blood to the lungs, the pulmonary capillaries carrying it through them, and the pulmonary veins conveying it from them; (4) the muscles, bones, and cartilages concerned in producing the breathing movements.*

The Air Passages.—Air reaches the pharynx through the nose or mouth (Fig. 1). On the ventral side of the pharynx (Fig. 46) is an aperture through which it passes into the *larynx* or voice-box (*a*, Fig. 88), which lies in the upper part of the neck. From the larynx air passes on through the *windpipe* or *trachea*, which enters the chest, and in the upper part divides into a *right* and a *left bronchus*. Each bronchus enters a lung, and divides in it into a vast number of very small tubes, called the *bronchial tubes*. The last and smallest bronchial tubes (*a*, Fig. 89) open into subdivided elastic sacs (*b*, *c*) with pouched walls.

Structure of the Trachea and its Branches.—The trachea, bronchi, and bronchial tubes are lined by mucous membrane, outside of which is a supporting stratum composed of connec-

* To these should be added (5) the nerve centres and nerves which control the muscles of respiration, and which will be subsequently considered (see Chap. XX).

tive and plain muscular tissues. Their walls also contain incomplete rings of cartilage which keep them open. Below the larynx the stiff windpipe passing down to the top of the chest may readily be felt in thin persons.

The Cilia of the Air Passages.—The mucous membrane

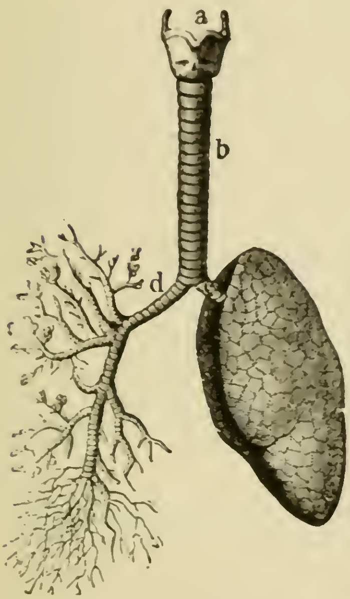

FIG. 88.

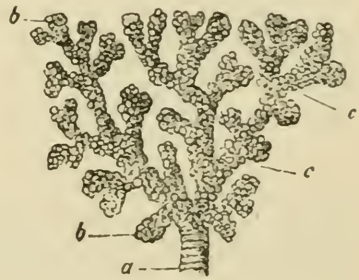

FIG. 89.

FIG. 88.—The lungs and air passages seen from the front. On the left of the figure the pulmonary tissue has been dissected away to show the ramifications of the bronchial tubes. *a*, larynx; *b*, trachea; *d*, right bronchus. The left bronchus is seen entering the *root* of its lung.

FIG. 89.—A small bronchial tube, *a*, dividing into its terminal branches, *c*; these have pouched or sacculated walls and end in the sacculated alveoli, *b*.

of the trachea and its branches, except the smallest, has a layer of *ciliated cells* on its surface. Each of these cells has on its end turned towards the cavity of the tube a tuft of from twenty to thirty slender threads which are in constant motion: they lash forcibly toward the throat, move gently back again, and then once more violently toward the outlet of the air passage. These moving threads are called *cilia*. Swaying in the

mucus secreted by the membrane which they line, they sweep it on to the larynx, where it is coughed up.

Imagine a man rowing in a boat at anchor. The sweep of the oars will drive the water back and not the boat forward. So these little oars, the cilia, anchored on the mucous membrane, drive on the secretion which bathes its surface.

Bronchitis, or "a cold on the chest," is an inflammation of the membrane lining the bronchial tubes, in consequence of which it swells, and its secretion is changed

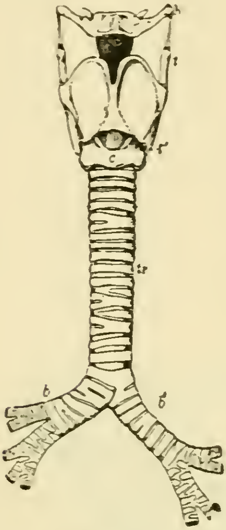

FIG. 90.

FIG. 91.

FIG. 90.—The trachea, front. *h*, hyoid bone; *tt'*, thyroid cartilage; *c*, cricoid; *e*, epiglottis; *tr*, trachea; *b* and *b'*, bronchi.
FIG. 91.—Ciliated cells from the epithelium.

in quantity and character. The swelling and secretion tend to close the tubes and interfere with the free passage of air in breathing.

The Lungs consist of the bronchial tubes and their terminal dilatations, together with blood vessels, lymphatics, and nerves, all bound firmly together by elastic tissue. The expansions called air sacs or *alveoli*, at the end of each final branch (Figs. 92 and 93), are relatively very large, and their surface is still further increased by the pouches which project from them. Their walls are highly elastic, and contain a close network of capillary blood vessels, supplied by the pulmonary artery and emptying into the pulmonary veins.

Through the extremely thin lining of the air sac, and the thin wall of the capillaries imbedded in it, oxygen is absorbed by the blood from the air in the air sac and carbon dioxide given up to it. It has been calculated that if the walls of the air cells were spread out flat and placed side by side they would cover an area of 2600 square feet. This great surface, therefore, represents the area of the body by which oxygen is received and carbon dioxide given off, and accounts for the rapidity with which the exchange takes place.

FIG. 91.—Two alveoli of the lung highly magnified. *b, b*, the *air cells*, or hollow protrusions of the alveolus, opening into its central cavity; *c*, terminal branches of bronchial tube.

The Pleuræ.—The exterior of each lung, except where its bronchus and blood vessels enter it, is covered by a thin elastic serous membrane, *the pleura* (Fig. 2), which closely resembles the peritoneum. This membrane also lines the inside of the chest. Its surface in health is kept moist by a small quantity of lymph. In consequence of its smoothness

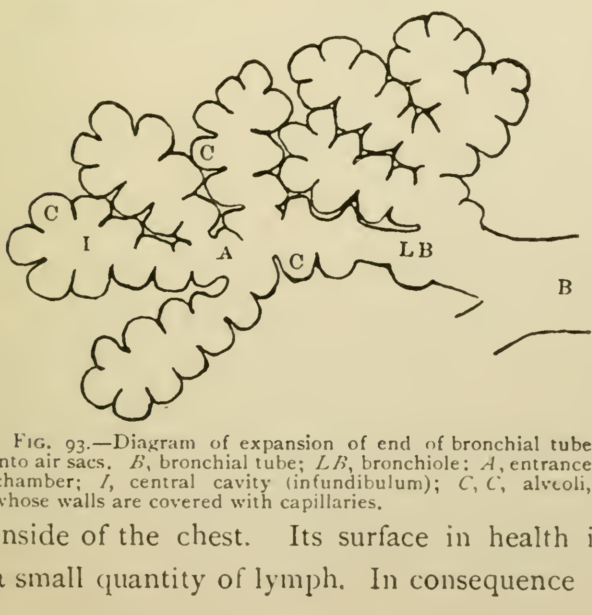

FIG. 93.—Diagram of expansion of end of bronchial tube into air sacs. *B*, bronchial tube; *LB*, bronchiole; *A*, entrance chamber; *I*, central cavity (infundibulum); *C, C*, alveoli, whose walls are covered with capillaries.

and moisture, the lungs glide over the chest wall during the breathing movements with but little friction.

Pleurisy is inflammation of the pleura. In its early stages

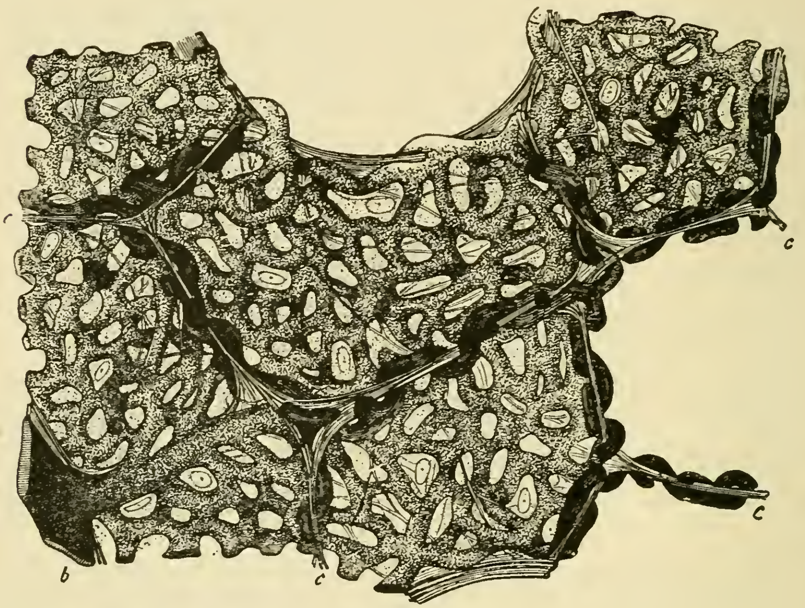

FIG. 94.—Section of lung with distended blood vessels, highly magnified. *c*, *c*, partitions between alveoli; *b*, small artery giving off capillaries to alveoli.

it is usually associated with sharp pain on drawing the breath. Later on a large quantity of lymph is often poured out by the inflamed pleura, taking up space which should be occupied by the lung.

The Elasticity of the Lungs.—The lungs are as elastic as a thin rubber bag. If we tie a tube tightly into a bronchus and blow in air the lung will dilate, but as soon as we cease blowing and leave the tube open, it will shrink up again. Yet in the chest the lungs always remain so expanded as completely to fill all the space left for them by the heart and other structures contained in the thorax.

Inspiration and Expiration.—The process of taking air

into the lungs is known as *inspiration*, that of expelling it as *expiration*. On the average, fifteen to eighteen inspirations and expirations occur in each minute. We therefore breathe in and out about once for every four beats of the heart.

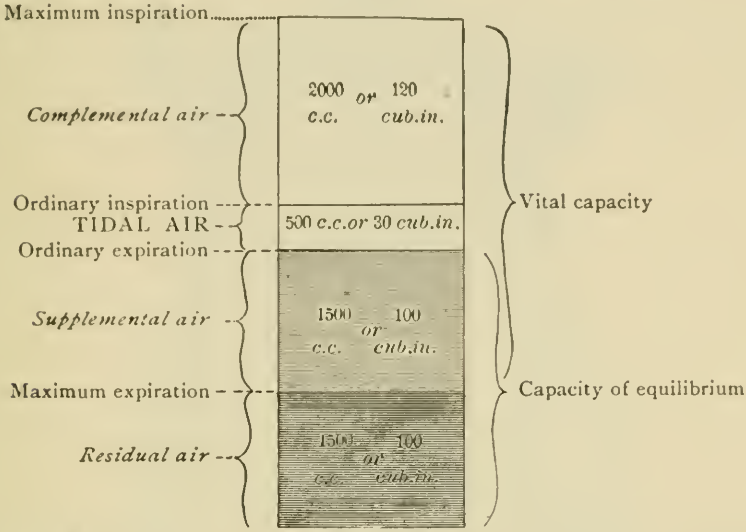

FIG. 95.—Amounts of air contained by the lungs in various phases of ordinary and of forced respiration.

Quantity of Air Breathed.—During ordinary quiet respiration, we inspire and expire about 30 cubic inches, or about one pint, of air; this is called the *tidal air*. After an expiration of this amount, we can still expire by effort about 100 cubic inches of air; this is called the *supplemental air*. There still remains in the lungs about 100 cubic inches of air which cannot be expelled with the most violent effort; this is the *residual air*. When breathing quietly, it is possible, after an inspiration of the ordinary 30 cubic inches of air, to inspire an additional 120 cubic inches; this is the *complemental air*. The total amount of air that can be expired after the deepest inspiration possible is called the *vital capacity*. This varies in different individuals and depends largely on the movability of the chest wall.

The Structure of the Thorax.—The thorax is a conical cavity with a supporting skeleton (Fig. 96) formed by the

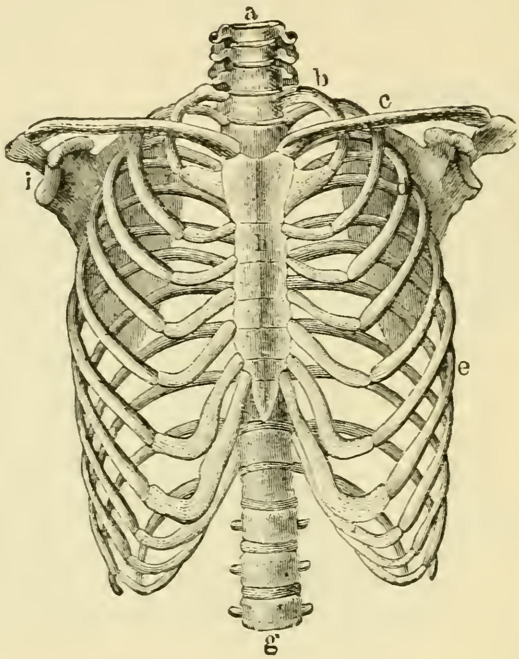

FIG. 96.—The skeleton of the thorax. *a*, *g*, vertebral column ; *b*, first rib ; *c*, clavicle ; *d*, third rib ; *i*, glenoid fossa.

dorsal vertebræ behind, the breast bone in front, and the ribs and rib cartilages on the sides. Between and over these lie muscles, and the whole is covered air-tight by the skin outside and the pleuræ (p. 197) inside. Above, it is closed by the muscles and other organs of the neck; below by a movable bottom, the diaphragm. The air-tight chamber thus enclosed can be enlarged in all three diameters, but especially in the vertical, and in the dorso-ventral (running from the spinal column to the breast bone).

The Vertical Enlargement of the Thorax is brought about by the contraction of the diaphragm (Fig. 97), a thin sheet of muscle, with a fibrous membrane in its centre serving

as a tendon. In rest the diaphragm is dome-shaped, its concavity being turned towards the abdomen. From the tendon on the crown of the dome, striped muscular fibres radiate, downward and outward, in all directions, and are fixed by their outer ends to the six lower ribs, the breast bone, and the vertebral column. In inspiration the muscular fibres, by shortening, flatten the dome and enlarge the thoracic cavity

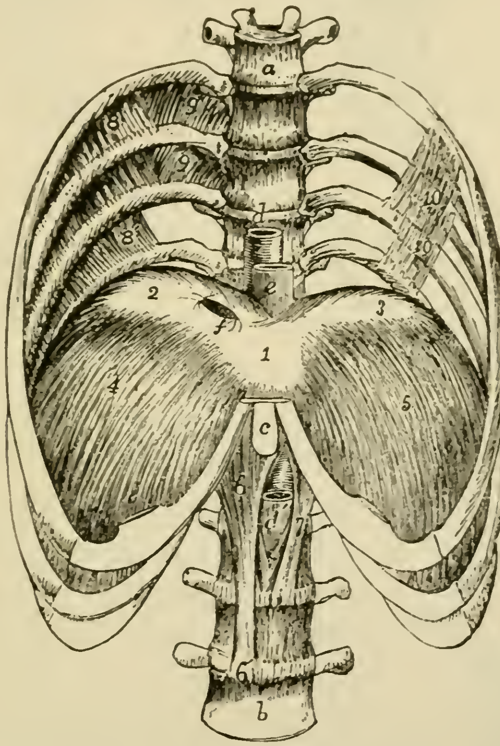

FIG. 97.—The lower half of the thorax, with four lumbar vertebræ, showing the diaphragm from above. 1, 2, 3, central tendon; 4, 5, muscular part.

of the diaphragm by adding space to its widest part (Fig. 98).

Since the abdominal cavity is surrounded by bony and dense muscular walls, except in front where they are thin and elastic, the downward movement of the diaphragm manifests itself as an outward movement of the front abdominal wall.

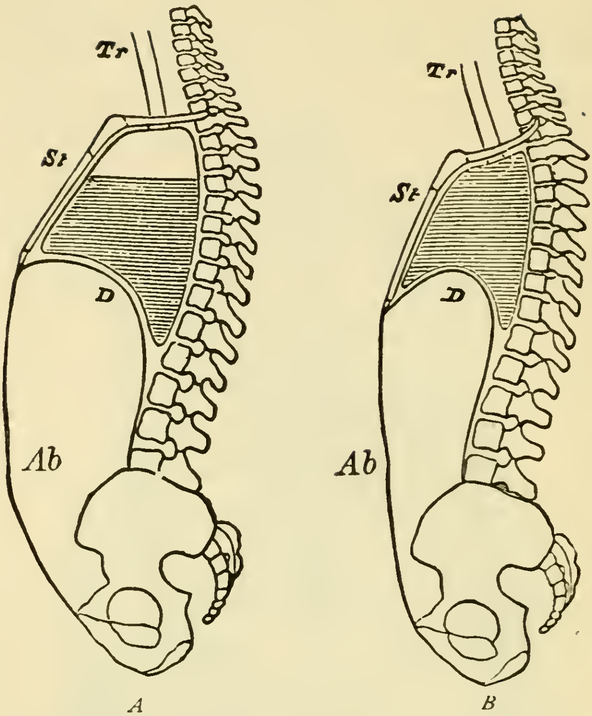

FIG. 98.—Diagram to show the changes in the sternum, diaphragm, and abdominal wall in respiration. *A*, inspiration; *B*, expiration; *Tr*, trachea; *St*, sternum; *D*, diaphragm; *Ab*, abdominal wall. The shaded part is to indicate the stationary air.

The Dorso-Ventral Enlargement of the Thorax.—The ribs slope downward (Fig. 15) from the vertebral column to the breast bone, the slope being most marked in the lower ones. During inspiration the breast bone and the sternal ends of the ribs attached to it are raised by muscles which pull on them, thus increasing the distance between the sternum and the vertebral column. That this must be so will readily be seen by examining the diagram Fig. 99, where *ab* represents the vertebral column, *c* and *d* two ribs, and *st* the sterum.

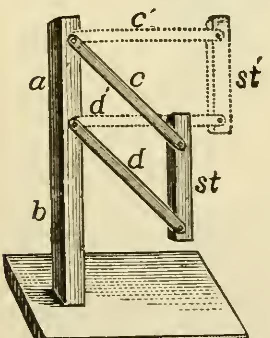

FIG. 99.—Diagram illustrating the dorso ventral increase in the diameter of the thorax when the ribs are raised.

The continuous lines represent the natural position of the ribs at rest in expiration, and the dotted lines the position in inspiration. It is clear that when their lower ends are raised so as to make the bars lie in a more nearly horizontal plane, the sternum is pushed away from the spine, and the extent of the chest cavity between backbone and breast bone is increased.

Inspiration requires a good deal of muscular effort. When the diaphragm contracts and flattens its dome, it has to push down the abdominal viscera on its under side, and to press out the front wall of the abdomen to make room for them. The ribs, shoulders, and breast bone have also to be lifted up and the elasticity of the lungs overcome.

Expiration.—In ordinary expiration, on the contrary, no muscular effort is required. As soon as the muscles which have raised the ribs and sternum relax, these bones return by their weight and the elasticity of the rib cartilages to their former unconstrained position. The elastic abdominal wall presses the abdominal viscera against the under side of the diaphragm and pushes it up again, as soon as its muscular fibres cease contracting. In this way the chest cavity is restored to its original capacity, and the air is sent out of the lungs rather by the elasticity and weight of the parts which were stretched and raised in inspiration than by any special expiratory effort.

When, however, an expiration is violent, as during a sneeze or a fit of coughing, the abdominal muscles act as special expiratory muscles by pulling down the ribs and pressing up the diaphragm.

The Respiratory Sounds.—The entry and exit of air are accompanied by *respiratory sounds* or *murmurs*, which can be heard on applying the ear to the chest wall. These sounds are characteristic over the trachea, the larger bronchial tubes,

and portions of lung from which large bronchial tubes are absent. They are variously modified in pulmonary affections, and hence the value of *auscultation* of the lungs in assisting the physician to form a diagnosis.

Why the Lungs fill with Air may be best understood by considering a pair of bellows, as shown in Fig. 100. A thin-walled rubber bag (*b*) is fitted loosely inside the bellows and connected with the outside air only through its nozzle (*c*). It is possible to fill the rubber bag either by blowing air in through the nozzle, or by opening the bellows. When the rubber bag is filled with air, it is possible to empty it either by closing the bellows or by releasing the handles and allowing the weight of the bellows and the elasticity of the bag to force the air out. Whenever the cavity of the bellows is made larger, air enters the rubber bag; when made smaller, air passes out from the bag. When the bellows are being opened, air enters the cavity; since it is impossible to pull air, this inward movement means that air is being pushed in. When the bellows are being closed the outward movement of air indicates similarly that there is a force behind it pushing it out.*

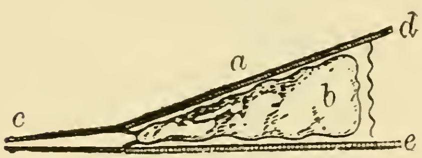

FIG. 100.—Diagram to illustrate the entry of air to the lungs when the thoracic cavity enlarges.

* It must be remembered that we are at the bottom of a sea of air and that this sea is pressing on all exposed surfaces with a force equal to about 15 lbs. to the square inch of surface, but as it presses equally on all sides of objects, the pressures in opposite directions neutralize each other and we do not notice their presence. As, for example, when we have a piece of thin sheet rubber, it is perfectly flaccid. If, however, we diminish the pressure upon one side by putting the rubber over the mouth and inhaling, the pressure upon the other side, though unchanged, is relatively greater and pushes the membrane in.

It is thus apparent that so long as air cannot enter between the walls of the rubber bag and the bellows, the rubber bag will follow the movements of the bellows and be emptied only when the bellows are closed. The chest walls correspond to the bellows and the lungs to the inner rubber bag. We thus see why the lungs cannot completely empty themselves during life, since the chest wall is not sufficiently flexible to close down upon them so far as to obliterate the cavity. If, however, the chest wall becomes punctured, as by a wound, connecting the chest cavity with the external air, the external air pressure, no longer withheld from the lung's surface by the chest wall, presses upon it and neutralizes the pressure of the air within the lung which has kept it expanded ; the lung's elasticity then causes it to collapse to a small flaccid mass.

The Nervous Control of Respiration.—The respiratory movements are produced by contractions of muscles and are controlled by the action of nerves. It has been found that the nervous impulses which give rise to the respiratory movements are controlled in part by a nervous centre in the spinal bulb, called the *respiratory centre.* Its activity seems to depend upon the condition of the blood ; when the blood is poor in oxygen and rich in carbon dioxide and other waste matters, this centre, as also the heart centre, becomes active and produces more rapid and deeper contractions of the respiratory muscles; when the blood is rich in oxygen and poor in wastes, the centre is more quiescent. During vigorous exercise, oxygen is used up rapidly from the blood and the respiratory centre is kept in a state of greater activity. During sleep, oxygen is used up more slowly and the respiratory movements are less frequent.

Hygienic Remarks.—Since the diaphragm when it con-

tracts pushes down the abdominal viscera lying against its under side, these have to make room for themselves by pushing out the soft front of the abdomen, which accordingly protrudes when the diaphragm descends. Hence breathing by the diaphragm is indicated on the exterior by movements of

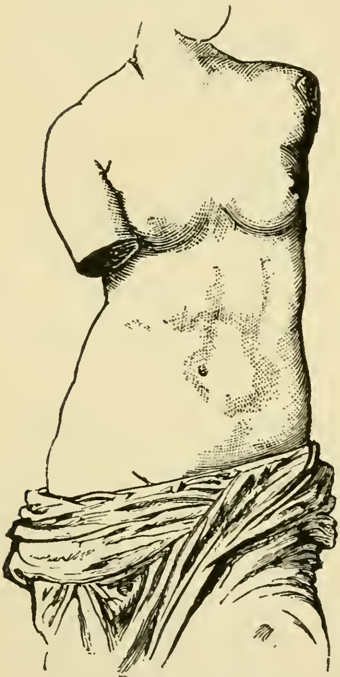

FIG. 101.—Torso of the Statue known as Venus of Milo.

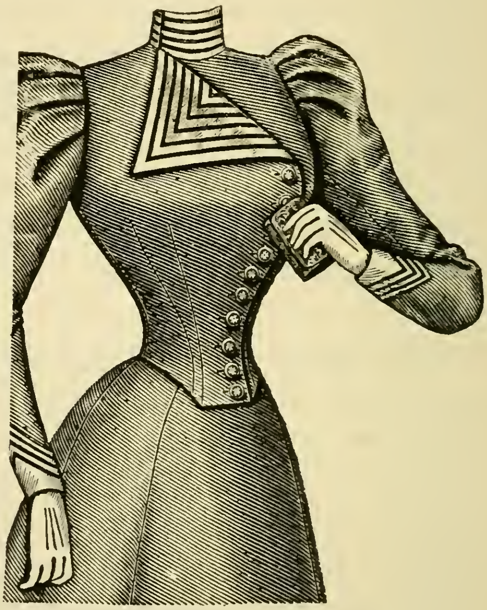

FIG. 102.—New York Fashion, 1898.

the abdomen (Fig. 98) and is often called "abdominal respiration," as distinguished from breathing by the ribs, called "costal" or "chest breathing." As a rule, men and children use the ribs less than adult women. Since abdomen and chest alternately expand and contract in healthy breathing, anything which impedes their free movement is to be avoided. The tight lacing which is still indulged in by those who think a distorted form beautiful, seriously impedes one of the most important functions of the body, and leads not

only to shortness of breath and an incapacity for muscular exertion, but in many cases to actual deformity or disease. The abdominal organs are compressed and forced downward, and as a result their attachments are stretched and their functions impeded. In extreme cases of tight lacing some organs are often directly injured; for example, weals of fibrous tissue are found developed on the liver from the constant pressure of the lower ribs forced against it.

Tight-vest -
cannot store up O, [illegible]
necessary to have large lung power

CHAPTER XVII.

THE CHEMISTRY OF RESPIRATION AND VENTILATION.

The Quantity of Air breathed daily.—After an ordinary expiration the chest cavity is by no means completely collapsed, as the lungs still contain about 200 cubic inches of air. In the next inspiration 30 more cubic inches are taken in, at the following expiration about the same amount is sent out, and so on throughout the day. During quiet breathing the quantity of air in the lungs varies, therefore, with each inspiration and expiration between 230 and 200 cubic inches. At each inspiration something over a pint of fresh air is taken in, and at each expiration about the same amount of vitiated air is expelled. As each of us breathes at least fifteen times a minute, we thus use each minute $15 \times 30 = 450$ cubic inches ($15\frac{1}{2}$ pints) of air. In an hour the quantity is $450 \times 60 = 27{,}000$ cubic inches (930 pints), and in twenty-four hours $27{,}000 \times 24 = 648{,}000$ cubic inches (22,320 pints) of air, which weighs about 28.7 lbs. We have next to see what it is that happens to this vast quantity of air breathed daily by each one of us; what we have taken out of it, and what we have given off to it.

The Changes produced in Air by being once breathed.—These are fourfold—changes in temperature, moisture, volume, and in its chemical composition.

Changes in Temperature.—The air taken into the lungs is nearly always cooler than that expired, which has a tem-

perature of about 36° C. (97° F.). The temperature of a room is usually about 21° C. (70° F.). The warmer the inspired air, the less the heat which is lost by the body in the breathing process.

Changes in Moisture.—Inspired air always contains more or less water vapor, but is rarely saturated—that is, rarely contains all it can take up without showing it as mist. The warmer air is, the water vapor it requires to saturate it. The expired air is nearly saturated at the temperature at which it leaves the body. This is shown by the moisture deposited when it is cooled, as on a mirror, or in the clouds formed by the breath on a frosty day. We therefore conclude that air when breathed gains water vapor and carries it off from the lungs. The quantity of water thus removed from the body is about nine ounces each twenty-four hours.

Changes in Volume.—If the expired air is measured as it leaves the body, its bulk will be found greater than that of the inspired air, since it not only has water vapor added to it, but is expanded in consequence of its higher temperature. If, however, it is dried and reduced to the same temperature as the inspired air, its volume will be found diminished, since it has lost 5.4 volumes of oxygen for every 4.3 volumes of carbon dioxide which it has gained.

Chemical Changes.—The most important changes brought about in the breathed air are those in its chemical composition. Pure air when completely dried consists in 100 parts of—

	By Volume.	By Weight.
Oxygen	20.8	23
Nitrogen	79.2	77

When breathed once, such air gains rather more than 4 volumes in 100 of carbon dioxide, and loses rather more than

5 of oxygen. More accurately, 100 volumes of expired air, when dried, consist of—

Oxygen	15.4
Nitrogen	79.2
Carbon dioxide	4.3

The expired air also contains volatile organic substances in quantities too minute for chemical analysis, but readily detected by the nose upon coming into a close room in which a number of persons have been collected.

The Quantity of Oxygen taken up by the Lungs in a Day.—We have already seen that the quantity of air breathed in a day is 648,000 cubic inches. This loses 5.4 per cent of oxygen or 35,000 cubic inches, weighing 12,818 grains ($1\frac{4}{5}$ lbs.). The body therefore gains this amount of oxygen through the lungs daily.

The Amount of Carbon Dioxide passed Out from the Lungs in a Day is 4.3 per cent of the total bulk of the air breathed, or 27,864 cubic inches; it weighs 14,105 grains or about 2 lbs.

We thus find that though each breath seems in itself a very little thing, the total amount of matter received into and passed out of the body through the lungs every day of our lives is considerable. In a year each adult breathes about 10,000 lbs. of air; from it he takes 657 lbs. of oxygen, and to it he gives off 730 lbs. of carbon dioxide.

Ventilation.—Since at each breath some oxygen is taken from the air and some carbon dioxide given to it, were the atmosphere around a living man not renewed he would at last be unable to get from the air the oxygen he required; he would die of oxygen starvation or be *suffocated*, as such a mode of death is called, as surely, though not quite so fast, as if he were put under the receiver of an air pump and all

the air around him removed. Hence the necessity of *ventilation* to supply fresh air in place of that breathed. Clearly the amount of fresh air requisite must be determined by the number of persons collected in a room. Moreover, since gas and lamps use oxygen and give out carbon dioxide, calculation must be made for them in arranging for the ventilation of a building in which they are to be used.

When Breathed Air becomes unwholesome.—The evil results of insufficient air supply are not ordinarily directly due to a lack of oxygen, for the blood flowing through the lungs can take the necessary amount of oxygen from air containing as little as fifteen or even ten per cent. The headache and drowsiness which result from sitting in badly ventilated rooms, and the lack of energy and general ill-health which accompany permanent living in such conditions, are dependent on a slow poisoning of the body by the reabsorption of matters eliminated from the lungs in previous respirations. What these are is not accurately known; they doubtless belong to those volatile bodies mentioned above as carried off in small quantities in each breath, since observation shows that the air becomes injurious long before the reduction of oxygen and the increase of carbon dioxide are sufficient to do any harm. Breathing air which contains one or two per cent of carbon dioxide produced by ordinary chemical methods does no injury, but the breathing of air containing one per cent of carbon dioxide produced by respiration is decidedly injurious, because of the organic materials sent out from the lungs at the same time.

The percentage of carbon dioxide in the air may be readily measured, whereas the more dangerous organic substances contained in expired air cannot be. These poisonous materials, however, always bear practically the same relation to the

amount of carbon dioxide; hence if carbon dioxide is estimated, the badness of the air, due to the poisonous factors, may be inferred. It must be remembered, however, that this applies to the carbon dioxide produced by respiration, and not to that produced by the burning of gas or lamps; hence in rooms lighted by these means allowance must be made, after determining the amount of carbon dioxide, for that which has been produced through their agency. When a very large amount of carbon dioxide is present the air cannot be safely respired, as, for example, at the bottom of wells or in brewing vats. This is due to two factors, the absence of oxygen and the presence of an overwhelming amount of carbon dioxide.

The Quantity of Fresh Air which should be allowed for each Person in a Room.—A man at rest expires air containing 4% of carbon dioxide, amounting in one hour to about $\frac{3}{5}$ cubic foot. It is agreed by hygienists that 2 parts of respiratory carbon dioxide in 10,000 parts of air are all that are permissible for respiration. Hence air must be introduced into an occupied room in sufficient amount to reduce the respiratory impurity of 4% or 400 parts in 10,000 to 2 parts; therefore there must be added to each breath 200 parts of fresh air, or 3000 cubic feet of air per hour for each individual.

Many experiments have shown that there should be an allowance of about 600 cubic feet of space for each man in the room. This permits the requisite change of air without drafts, and insures a chance for the thorough mixing of expired air with the air of the room so that it will not be rebreathed before mixing.

The nose of a person entering a room from the outside air has been found to be an excellent test of the purity of the air,

and any odor or sense of closeness detected in this way suggests that the air contains too much impurity to be breathed with safety. The accompanying table shows the relation between the determinations made by the sense of smell and the chemical analysis of the amount of carbon dioxide due to respiratory impurity present.

RELATION OF ORGANIC MATTER TO CARBON DIOXIDE, DETERMINED BY ODOR.

Condition of the air of an occupied room as determined by the nose.	1. Fresh, or not differing sensibly from the outer air.	2. Rather close. Organic matter becoming perceptible.	3. Close. Organic matter disagreeable.	4. Very close. Organic matter offensive and oppressive.
Corresponding parts of CO_2 in 10,000 vols. of air due to respiratory impurity.......	2	4	6.5	9
Total parts of CO_2 in 10,000 vols. of air (= + 4 parts atmospheric CO_2)...........	6	8	10.5	13

How to Ventilate.—Ventilation does not necessarily mean draughts of cold air, as is too often supposed. In warming by indirect radiation, as by furnace or steam pipes in the basement, proper ventilation may readily be secured by arranging openings connected with a chimney, by which the impure air may pass out to make room for the fresh warm air to enter. Since the fresh air is the warmest air of the room it goes immediately to the ceiling and will pass out through any openings it finds there. Hence all outlets should be at the floor level and the inlets for warm air at the ceiling. An open fire in a room will always keep up a current of air through it, and is one of the most wholesome, though not most economical, methods of warming an apartment.

Ordinary stoves in a room contribute little to the ventilation, for they take only a small amount of air out of the room through the chimney and bring in as leakage around doors

Ventilating + heating churches —

and windows only as much as they take out ; hence if these rooms are occupied the air becomes quickly impure. Some stoves are provided with jackets inside of which fresh air may be admitted from outside. If there is no such provision, it is possible to fasten a board three or four inches wide, to fit under the lower sash of a window. Fresh air then enters by the opening between the two sashes at the middle of the window and diffuses through the room, usually without draft. This window should be opened on the windward side of the room so the air will surely enter. The window on the opposite side of the room may be opened at the bottom to allow the foul air to pass out. In this way the change of air in the room may be made continuous. Since, fortunately, few doors and windows fit quite tight, fresh air gets into closed rooms in tolerable abundance for one or two occupants.

Changes undergone by the Blood in the Lungs.—These are the exact reverse of those exhibited by the breathed air —what the air gains the blood loses, and *vice versa*. The blood loses heat, water, and carbon dioxide, and gains oxygen. These gains and losses are accompanied by a change of color from the dark purple which the blood exhibits in the pulmonary artery, to the bright scarlet of the oxyhæmoglobin in the pulmonary veins.

CHAPTER XVIII.

THE KIDNEYS AND THE SKIN.

General Arrangement of the Nitrogen-excreting Organs.—These organs are (1) the *kidneys*, the glands which secrete the urine; (2) the *ureters* or ducts of the kidneys, which carry the secretion to (3) the *urinary bladder*, a reservoir in which it accumulates and from which it is expelled from time to time through (4) the *urethra*, an exit tube. The general arrangement of these parts, as seen from behind, is shown in Fig. 103. The kidneys (*R*) lie at the back of the abdominal cavity, opposite the upper lumbar vertebræ, one on each side of the middle line. Each is a firm mass, with a convex outer and a concave inner border, and its upper end a little larger than the lower. From the abdominal aorta (*A*) a *renal artery* (*Ar*) enters the inner border of each kidney, to break up within it into finer branches, ultimately ending in capillaries. These unite to form the *renal veins* (*Vr*), one of which leaves each kidney and opens into the inferior vena cava (*Vc*). From the concave border of each kidney proceeds also the *ureter* (*U*), a slender tube opening below into the bladder (*Vu*) near its lower end. From the bladder proceeds the urethra (*Ua*). The channel of each ureter passes very obliquely through the wall of the bladder; accordingly if the

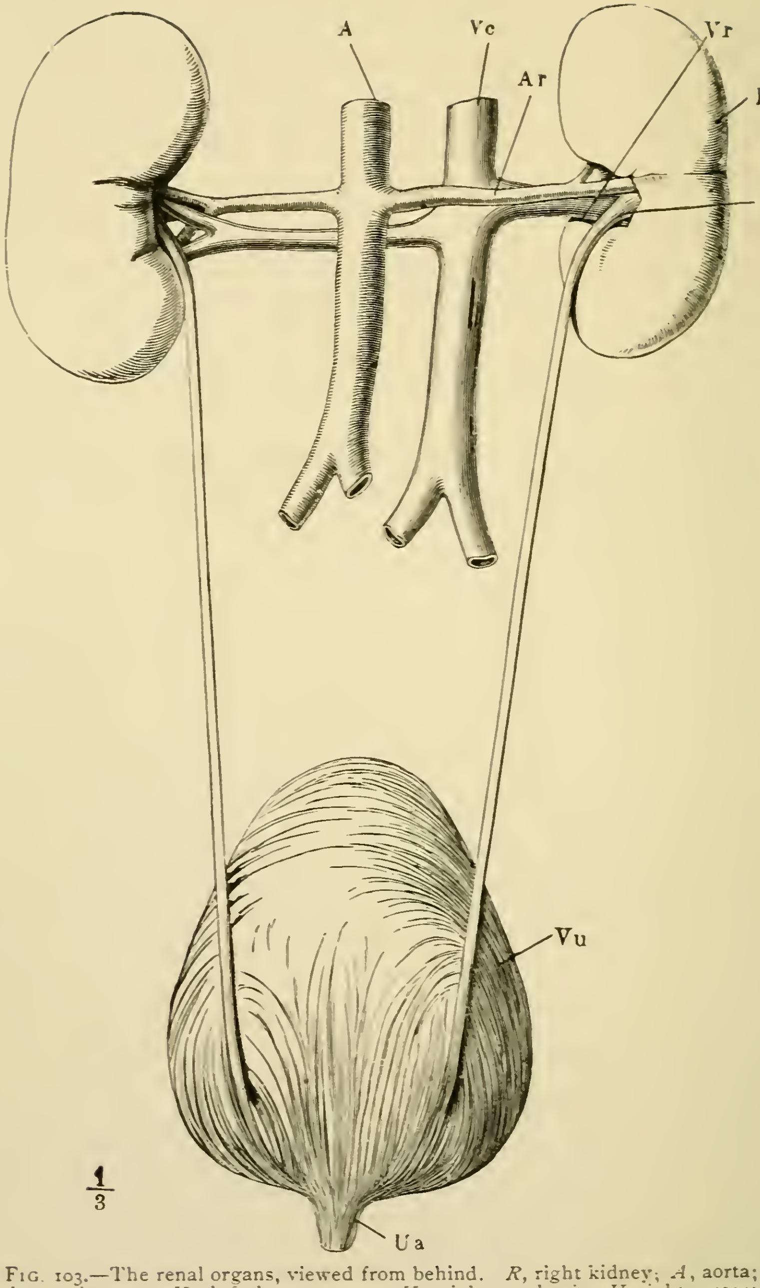

FIG. 103.—The renal organs, viewed from behind. *R*, right kidney; *A*, aorta; *Ar* right renal artery; *Vc*, inferior vena cava; *Vr*, right renal vein; *U*, right ureter; *Vu*, bladder; *Ua*, commencement of urethra.

pressure in the bladder rises above that of the liquid in the ureter the walls of the oblique passage are pressed together and it is closed. Usually the bladder (which contains muscular tissue in its walls) is relaxed, and the urine flows readily into it from the ureters. Since the passage of the urethra is kept closed by elastic tissue around the upper end, the urine accumulates in the bladder. When the bladder contracts and presses on its contents the ureters are closed in the way above indicated, the elasticity of the fibres closing the urethral exit from the bladder is overcome, and the liquid is forced out.

The Gross Structure of the Kidneys.—When a section is made through a kidney from its outer to its inner border (Fig. 104) it is seen that a deep fissure, the *hilus*, leads into it. In the hilus the ureter widens out to form the *pelvis of the kidney*, which breaks up into a number of smaller divisions, the cups or *calices*. The cut surface of the kidney proper is seen to consist of two distinct parts, an outer or *cortical portion*, and an inner or *medullary*. The medullary portion is less red and more glistening, is finely striated in a radial direction, and does not consist of one continuous mass, but of a number of conical portions, the *pyramids of Malpighi* (2′). Each of these pyramids is separated from its neighbors by a prolongation (*) of the cortical substance. This, however, does not reach to the apex of the pyramid, which projects, as the *papilla*, into a calyx of the ureter. At its outer end each pyramid separates into smaller portions (2″), separated by thin layers of cortex and gradually spreading everywhere into it. The cortical substance is redder and more granular-looking than the medullary. It forms everywhere the outer layer of the organ, besides dipping in between the pyramids in the manner above described.

The renal artery divides in the hilus into branches (5) which run into the kidney substance between the pyramids, giving

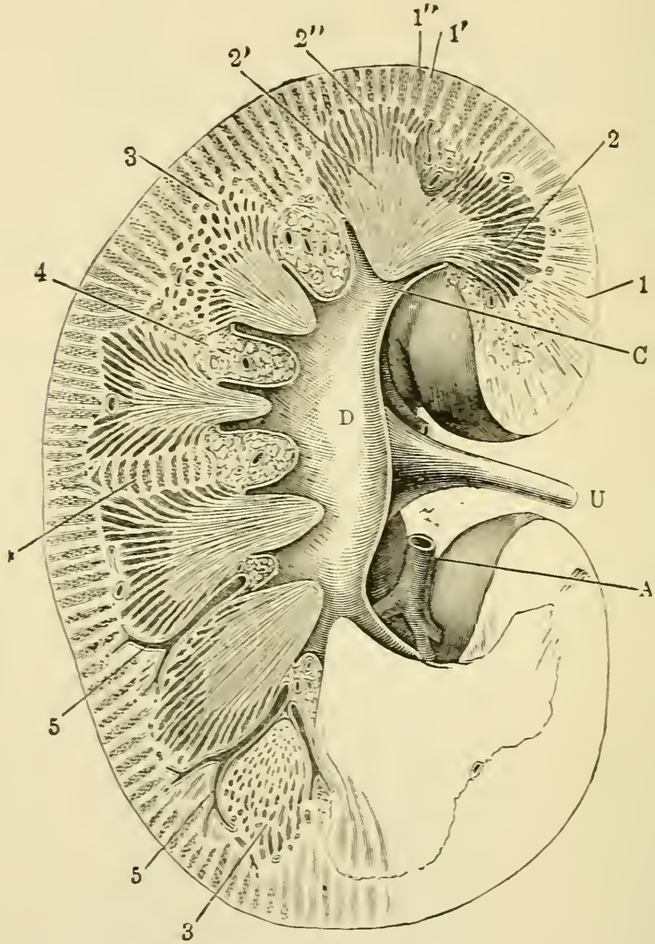

FIG. 104.—Section through the right kidney from its outer to its inner border. 1. cortex; 2, medulla; 2', pyramid of Malpighi; 2''. pyramid of Ferrein; 5, small branches of the renal artery entering between the pyramids; *A*, a branch of the renal artery; *C*. the pelvis of the kidney; *U*, ureter; *C*, a calyx.

off a few twigs to them, and end finally in a much closer vascular network in the cortex.

The Minute Structure of the Kidneys.—The kidneys are compound tubular glands, composed of branched microscopic

uriniferous tubules, lined by a single layer of secreting cells (Fig. 105), supported by connective tissue, and supplied with blood vessels, nerves, and lymphatics. Each of the final branches of each tubule ends in a dilatation which contains a knot of blood vessels (Fig. 106), through whose walls water and salts enter the tubule. As the water trickles along the tubules, their cells take the urea from the blood in the capillaries wrapped closely around them (Fig. 105). The tubules unite in the pyramids to form larger ducts, which pour the secretion into the calices of the pelvis of the ureter, which then conveys it to the bladder.

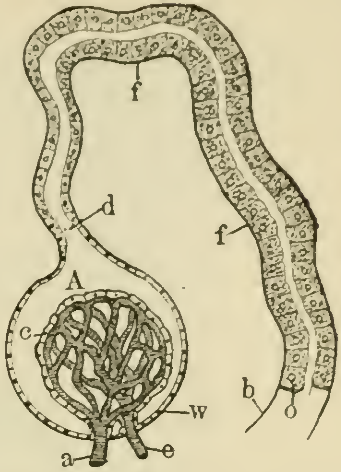

FIG. 105.—Diagram of a kidney glomerulus and the commencement of an uriniferous tubule *a*, afferent blood vessel pushing in the wall, *w*, of a Malpighian capsule and ending in the capillary tuft from which the vein *e* issues; *c*, involuted epithelium; for the sake of distinctness it is represented as a wrapping for the whole tuft; in nature it forms a close investment around each vessel of glomerulus; *A*, space in capsule; *d*, neck of capsule; *ff*, first convoluted portion of an uriniferous tubule; *o*, granular epithelial cells; *b*, basement membrane.

The Renal Secretion is a watery, acid solution of urea and inorganic salts. These solids amount to 4 per cent of the total secretion and give the solution an average specific gravity of 1.022. The urine excreted in twenty-four hours contains: urea, 35 gms. ($1\frac{1}{7}$ oz.); inorganic salts (chiefly sodium, potassium, ammonia, calcium, and magnesium), $26\frac{1}{2}$ gms. ($\frac{3}{4}$ oz.); and water, 1400 gms. (3 pints).

The urea, which is secreted by the kidneys and was formerly supposed to be formed there, is made by the liver as a final oxidation of nitrogenous materials which have been turned into the blood by the tissues. As the chief organs for the excretion of this nitrogenous waste, the kidneys are among the

most important of the body. Any defect in their healthy activity leads to serious trouble, due to the accumulation of nitrogenous wastes in the body.

The Skin, which covers the whole exterior of the body, consists everywhere of two distinct layers, an outer, the *cuticle*

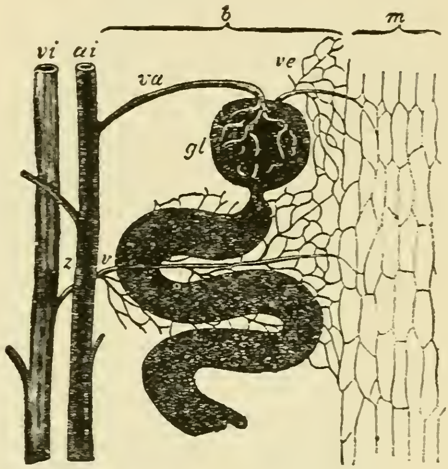

FIG. 106.—Circulation in the kidney. *ai*, small branch of renal artery giving off the branch *va*, which enters glomerulus, issues as *ve*, and then breaks up into capillaries, which after surrounding the tubule find their way by *v* into *vi*, branch of the renal vein; *m*, capillaries around tubules in parts of the cortical substance where there are no glomeruli.

or *epidermis*,* and an inner, the *dermis*. *Hairs* and *nails* are excessively developed parts of the epidermis.

The Epidermis (Fig. 107) consists of cells, arranged in many layers and united by a small amount of cementing substance. The deepest layer (*d*) is composed of elongated or *columnar* cells, set with their long axes perpendicular to the dermis beneath. It is succeeded by several strata of roundish cells (*b*), which in the outer layers become more and more

* A blister is due to the accumulation of liquid between layers of the epidermis.

flattened in a plane parallel to the surface. The outermost epidermic stratum is composed of many layers of much

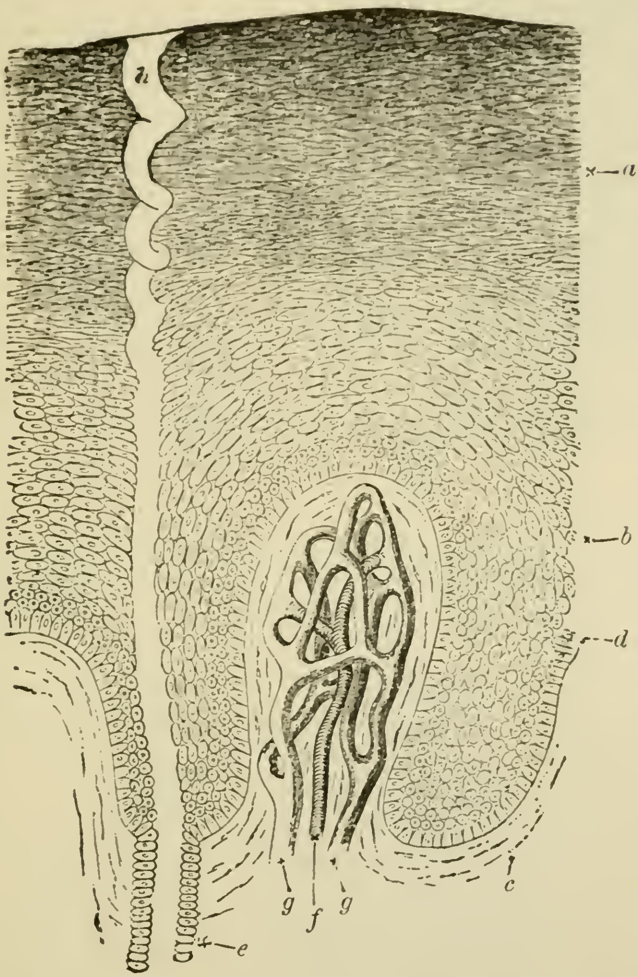

FIG. 107.—A section through the epidermis, somewhat diagrammatic, highly magnified. Below is seen a papilla of the dermis, with its artery, *f*, and veins, *gg*; *a*, the horny layer of the epidermis; *b*, the *rete muscosum* or Malpighian layer; *d*, the layer of columnar epidermic cells in immediate contact with the dermis; *h*, the duct of a sweat gland.

flattened cells from which the nuclei, conspicuous in the deeper layers, have disappeared. These superficial cells are dead, and are constantly being shed from the surface of the

body. Their place is taken by new cells, formed in the deeper layers, pushed up to the surface and flattened in their progress. The change in the form of the cells as they travel outward is accompanied by chemical changes; they finally constitute a semi-transparent dry *horny stratum* (*a*), distinct from a deeper, more opaque, and softer layer (*b* and *d*) of the epidermis.

FIG. 108.—Magnified view of the epidermis, showing mouths of the sweat glands.

The material which is peeled off the skin on rubbing it with a rough towel after a warm bath, consists of dead outer scales of the horny stratum of the epidermis.

Nerves penetrate the deeper layers of the epidermis, but no blood vessels enter it. The epidermis is also penetrated by the ducts of sweat glands, which have their mouths along the ridges (Fig. 108), and by the hairs. In dark races the color is due to a pigment contained chiefly in the deeper cells of the epidermis.

The Dermis, or **True Skin** (Fig. 109), consists of a close felt-work of connective tissue, which becomes wider meshed below and passes gradually into the *subcutaneous areolar tissue*. In texture it is much like damp raw cotton, and loosely attaches the skin to parts beneath. In tanning, the dermis is turned into leather, its connective tissue forming an insoluble and tough compound with the tannin of the oak-bark employed. Wherever there are hairs bundles of plain muscular tissue are found in the dermis; it contains also a close network of capillary blood vessels, and numerous lymphatics and nerves. In shaving, as long as the razor keeps

in the epidermis there is no bleeding; but a deeper cut shows at once the presence of blood vessels in the true skin.

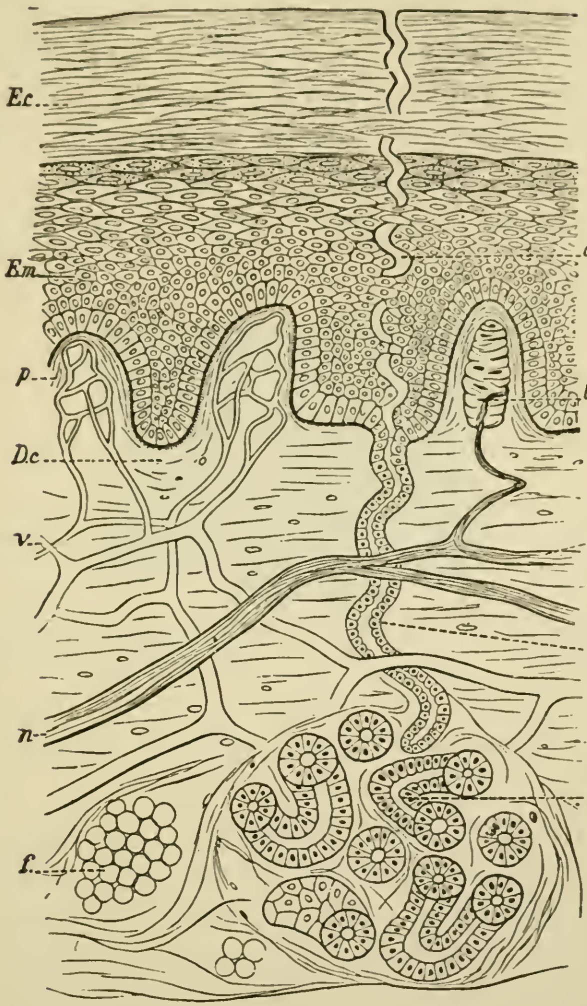

FIG. 109.—Diagram to show the structure of the skin. *E.c.* epidermis, corneous part; *E.m.* epidermis, Malpighian part; *D.c*, connective tissue of dermis; *p*, papilla; *gl*, sweat gland, the coils of the tube cut across or lengthwise; *d*, its duct; *f*, fat; *v*, blood vessels; *n*, nerve; *t.c*, tactile corpuscle.

The Papillæ of the Dermis.—The outer surface of the dermis is almost everywhere raised into minute elevations,

called *papillæ*, on which the epidermis is molded, so that its deep side presents pits corresponding to the projections of the dermis. In Fig. 108 are shown papillæ of the dermis containing a knot of blood-vessels, supplied by small arteries and having the blood carried off from them by little veins. Other papillæ contain no capillary loops, but, instead, special organs connected with nerve-fibres (*tactile corpuscles*), and concerned in the sense of touch. On the palm of the hand the dermic papillæ are especially well

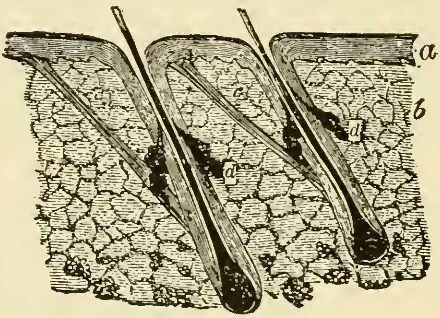

FIG. 110.—Section of the skin, showing the hair follicles, sebaceous glands, and the muscles of the hair. *a*, epidermis; *b*, dermis; *c*, muscles of the hair follicles; *d*, sebaceous glands.

developed, as they are in most parts where the sense of touch is acute, and are arranged in rows. The epidermis fills up the hollows between the papillæ of the same row, but dips down between adjacent rows, and thus produces the finer epidermic ridges.* On the thumbs and finger tips, these ridges, finely dotted by the mouths of the sweat ducts, assume more or less definite patterns. These patterns, which are different in each person, persist throughout life and are used for personal identification. The wrinkles of old persons are due to the absorption of subcutaneous fat and of

* The more marked furrows on the palm, the so-called "lines of life" of the gypsy's palmistry, have a different origin.

other soft parts beneath the skin, which does not shrink to the same extent and is therefore thrown into folds.

Hairs, longer or shorter, are found all over the surface of the body, except in a few regions, as the palms of the hands and the soles of the feet. A hair is a slender thread of epidermis, developed on a special dermic papilla placed at the bottom of a depression, formed by a pitting-in of the dermis. The depression is known as the *hair follicle*. The part of the hair buried in the follicle is called its *root*, and is succeeded by a *stem*, which (in uncut hairs) tapers off to a *point*. Each hair is made up of a number of epidermic cells, arranged together to form a fibre.*

Nails.—A nail is a part of the epidermis, with its horny stratum greatly developed. The back part of the nail fits into a furrow of the dermis, and is called its *root*. The visible part consists of a *body*, attached to the dermis beneath (which forms the *bed of the nail*), and of a *free edge*. Near the root is a little area, whiter than the rest of the nail, called the *lunula*. The whiteness is due in part to the greater opaqueness of the nail there, and partly to the less vascular character of its bed, which when seen through the nail causes its pink color.

The portion of the dermis on which the nail is formed is called its *matrix*. At the root of the nail is a groove, in which by the addition of new cells the nail grows in length. The part of the matrix lying beneath the body of the nail, called its *bed*, is highly vascular. New cells formed on its bed and added to its under surface cause the nail to increase in thickness, as it is pushed forward by the new growth at its root.

* The hairs of different races often present characteristic differences. The white races have cylindrical hair, whereas negroes have flattened or ribbon-like hair, hence its tendency to curl.

The free end of a nail is therefore its thickest part. If a nail is "cast" in consequence of an injury, or torn off, a new one is produced, provided the matrix is not destroyed.

The Glands of the Skin are of two kinds, *sweat* and *oil glands*.

The Sweat Glands (Figs. 108 and 111) are microscopic tubes which reach from the surface of the skin to the subcutaneous areolar tissue; there the tube often branches, and is coiled up into a little knot, intertwined with blood capillaries. These glands are found all over the skin, but are most abundant on the palms of the hands, the soles of the feet, and the brow. Altogether, there are about two and a half millions of them.

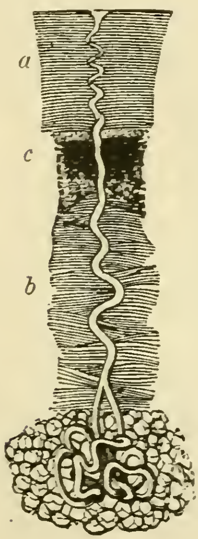

FIG. 111. — A sweat gland. *d*, horny layer of cuticle; *c*, Malpighian layer; *b*, dermis. The coils of the gland proper, imbedded in the subcutaneous fat, are seen below the dermis.

The perspiration or *sweat* poured out by these glands is a transparent colorless liquid, with a peculiar odor, varying in different races, and in different regions of the body. Its quantity in twenty-four hours is subject to great variations, but usually lies between 700 and 2000 grams (or 25 and 71 ounces). The amount is influenced mainly by the surrounding temperature, being greater when this is high; but it is also increased by other conditions tending to raise the temperature of the body, as muscular exercise.* The

* The secretion of perspiration is greatly increased during muscular exercise and is closely related to the heat control of the body, for during muscular exercise much more heat is produced in the body. By the evaporation of this extra amount of perspiration a large share of the heat is removed, keeping the body temperature at the normal point (98° 4 F.). In fever, the sweat glands do not act; as a result the skin is ordinarily dry and less heat is lost.

sweat may or may not evaporate as fast as it is secreted; in the former case it is known as *insensible*, in the latter as *sensible perspiration*. By far the most passes off in the insensible form; drops of sweat accumulate only when the secretion is very profuse, or the surrounding atmosphere so humid that it does not readily take up more moisture. The perspiration in 1000 parts contains 990 of water to 10 of solids. Among the latter is, in health, a little urea, some sodium chloride, and other salts. In diseased conditions of the kidneys, when they are not able to excrete all the urea of the blood, it collects in the blood and is excreted by the skin in greater amount than ordinarily. By causing profuse perspiration under such conditions, a considerable amount of urea can thus be eliminated from the system to supplement the impaired action of the kidneys.

The Sebaceous Glands usually open into hair follicles (Fig. 110). They are small compound racemose glands (p. 107). Each presents a duct, opening near the mouth of the hair follicle; when followed back this duct is found to divide into several branches which end in globular expansions, lined by secreting cells. The mouth of the ducts discharges into the hair follicle.

The Sebaceous Secretion is oily and semi-fluid. In healthy persons it lubricates the hair and renders it glossy. It is also spread more or less over all the surface of the skin, and makes it oily and less permeable by water.

The Skin as a Sense Organ.—Besides its functions as a protective covering and an excretory organ, the skin is of extreme importance, as being the seat of the dermal senses. (Chap. XXI.)

Hygiene of the Skin.—The sebaceous secretion and the

solid residue left by evaporating sweat form a film on the skin. Hence the importance of personal cleanliness. Exposed parts of the body except the scalp should be washed daily with good soap. The entire body should be washed with warm water and soap at least once or twice a week. If the skin becomes dry from too frequent bathing, the oil should be restored by use of vaseline, tallow or other emollient. No doubt many persons go about in very good health with very little washing; contact with the clothes and other external objects keeps the skin excretions from accumulating to any very great extent. But apart from the duty of personal cleanliness imposed on every one in daily intercourse with others, the greater immunity from infectious diseases afforded by cleanliness should be an important inducement. Undoubtedly the habit of washing the hands before eating is a most effective preventive measure.

Bathing.—One object of bathing is to cleanse the skin; another, to strengthen and invigorate the whole frame. For some strong healthy persons a cold bath may be the best; but in severe weather the temperature of the water should be raised to 15° C. (about 60° F.), at which it still feels quite cool to the surface. The first effect of a cold bath is to contract all the skin vessels and make the surface pallid. This is soon followed by a reaction, in which the skin becomes red and full of blood, and a glow of warmth is felt. The proper time to come out of the bath is while this reaction lasts, and it should be promoted by a good rubbing. If the stay in the cold water is too prolonged, the state of reaction passes off, the skin again becomes pallid, and the person feels cold, uncomfortable, and depressed all day. Such bathing is injurious instead of beneficial, since it lowers instead of stimulating the activities of the body. How long one may remain in cold

sea water with benefit depends greatly on the individual ; a vigorous man can bear and set up a healthy reaction after ten or twenty minutes' immersion, whereas a feeble person may be exhausted by one minute's exposure. Of course, apart from this, the temperature of the water is of great importance. Water which feels cold to the skin may vary within very wide limits of temperature. The colder it is, the shorter the time which it is wise to remain in it.

When to Bathe.—It is perfectly safe to bathe when warm, in spite of the common belief. No one should enter a cold bath when feeling chilly, when in a depressed vital condition, or immediately after a meal. The best time for a long cold bath is two or three hours after breakfast or the mid-day meal. For a brief daily dip there is no better time than on rising in the morning.

Shower Baths are coming into general use because of their convenience and economy of water. They may be supplied with warm or cold water and are effective for both cleanliness and stimulation. The cold shower is far better than the cold plunge, since it stimulates both by the coolness of the water and the force with which it comes against the skin. At the same time it does not chill the body nor lead to depression by abstracting a large amount of heat.

Prolonged Warm Baths, except occasionally for purposes of cleanliness, are medical remedies, and not proper for daily use. While promoting the tendency to perspiration (often important in disease), they also, if often repeated, lower the general vigor of the body.

CHAPTER XIX.

WHY WE NEED A NERVOUS SYSTEM. ITS ANATOMY.

The Harmonious Co-operation of the Organs of the Body. —We have already learned that the body consists of a vast number of cells and fibres, combined to form organs, and that each kind of cell or fibre and each organ has its own peculiar structure, properties, and uses. Except in so far as the blood, passing from organ to organ, carries matters from one to another, and indirectly enables each organ to act upon the rest, we have not as yet studied the means by which all this collection of organs is made to work together, so that each shall not merely look after itself, but regulate its activity in relation to the needs or dangers of the others.

That the organs do co-operate we all know. When an object threatens to touch the eye, the lids involuntarily shut. When we are using the muscles of the legs vigorously the muscles of respiration hurry their action, that oxygen may be conveyed more rapidly to the blood for the supply of the working leg muscles, and that the wastes produced by them may be quickly removed. When the sole of the foot is tickled the muscles of the thigh and leg, which are not directly interfered with at all, contract and jerk the foot away from its tormentor. Everywhere among the organs we find this co-operation through which our bodies are enabled to continue alive. In Æsop's fable we are told how the arms

and jaws declined to work any longer in providing and grinding food for the lazy stomach, and how they soon came to grief in consequence. We might extend the fable, and tell how afterwards the stomach made up its mind to digest and absorb just as much food as it wanted for itself, and not bother about supplying those cantankerous arms and jaws. If the stomach ceased to work for the other parts they soon would cease to be able to send food to it, and so it would itself starve in turn.

How a Man differs from a Collection of Living Organs.—Throughout the body, heart, lungs, stomach, intestines, liver, muscles, and skin, all need one another's aid to obtain food and oxygen, to remove wastes, and to avoid dangers. This co-operation makes the individual human being. A mere mass of living organs, arranged together in the form of man's body, but each acting without reference to the rest, would no more make a *man* than a mob of strong men would make an army. In the mob the reckless courage of some, the personal cowardice of others, the uncontrolled ambition of a few, would make the crowd nearly useless for military purposes in spite of the merits of its individual members. In the body, if the organs were not disciplined, controlled, and guided, so as to work together for the good of the whole, death would very soon result. As a matter of fact this is the way in which death almost always does begin. The body is not built like the deacon's "one-hoss shay," to run till every part of it gives out at the same moment. Some important organ ceases to do its part properly; as a consequence the whole complex mechanism is thrown out of gear, and death results.

Co-ordination means controlling and combining the activities of a number of working units (whether men, organs, or

machines) for the attainment of a definite end. A promiscuous and undirected crowd of competent bricklayers, carpenters, hod-carriers, and so forth, would be quite incompetent to build a house. There might be present abundant energy and skill to construct walls, floors, and roof; but if each man worked for himself and took no heed of the rest the result would be an odd building, if any at all. Hence the whole work is placed under the control of a master builder, who guides the activities of individuals according to the needs of the moment. The healthy body may be regarded as made up of a number of conscientious workers, the organs, who are concerned in building it and keeping it in repair, each one acting so as to co-operate with the rest for the attainment of the common end. The master builder is represented by the *nervous system*, which is in communication with all the other organs, is influenced by the condition and the needs of every part at each moment, and guides the activity of all accordingly. Part of this control is exercised consciously, but much more is carried on without our knowing anything about it.

Nerve Trunks and Nerve Centres.—In dissecting the body numerous white cords are found which at first sight might be taken for tendons. That they are something else soon becomes clear, since a great many of them have no connection with muscles, and those which have usually enter near the middle of the belly of the muscle, instead of being fixed to its ends as most tendons are. These cords are *nerve trunks*. If followed from the middle line of the body (Fig. 112) each will be found to break up into finer and finer branches, until the subdivisions become too small to be followed without the aid of a microscope. Traced towards the middle of the body the trunk will, in most cases, be found to increase by the union of others with it, and ultimately to join a much larger

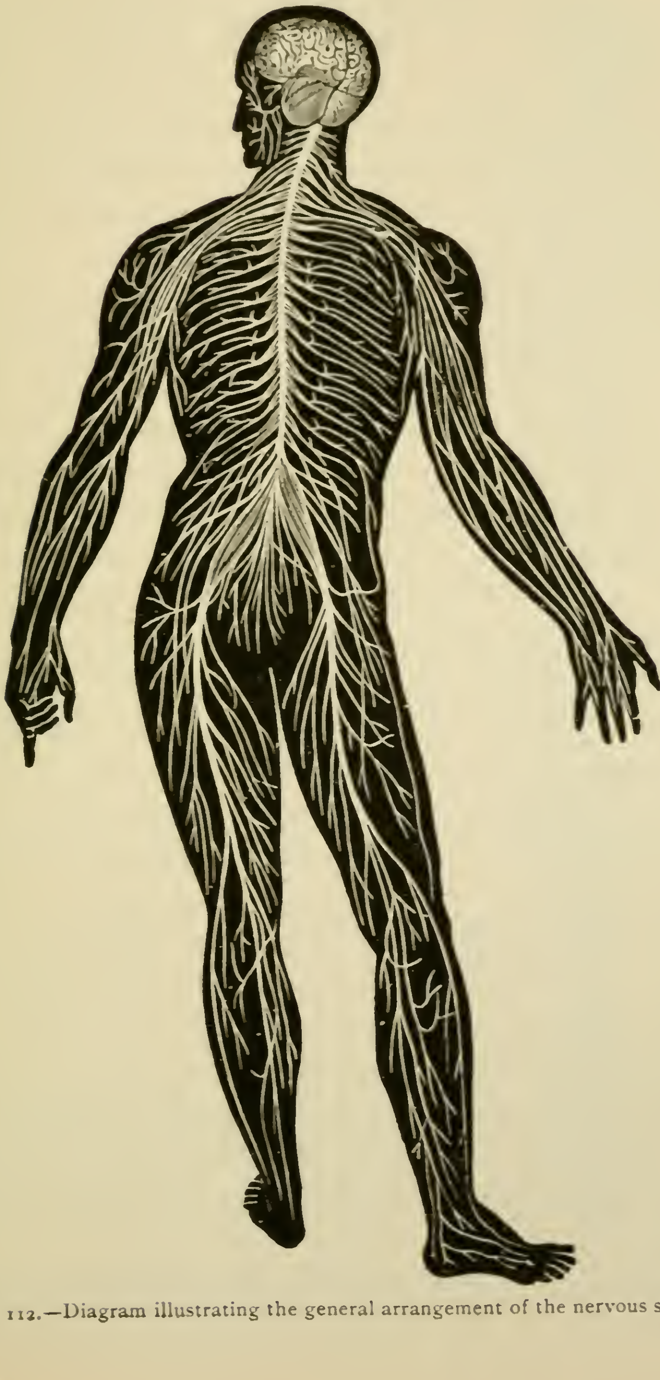

FIG. 112.—Diagram illustrating the general arrangement of the nervous system.

mass of different structure (spinal cord, or brain). The inner end of a nerve is its *proximal*, and the other its *distal* or *peripheral end.*

Nerve trunks radiate all over the body, branching and becoming smaller and smaller as they proceed; they end in or among the cells and fibres of the various organs. The general arrangement is shown in Fig. 112.

The Main Nerve Centres.—The great majority of the nerve trunks take their origin from the *brain* and *spinal cord*, which together form the great *cerebro-spinal centre.* Some nerves, however, commence in rounded or oval masses, which vary in size from that of the kernel of an almond down to microscopic dimensions, and which are widely distributed in the body. Each of these smaller centres is called a *ganglion.* A considerable number of the largest ganglia are united directly to one another by nerve trunks, and give off nerves especially to blood vessels and to the organs in the thoracic and abdominal cavities. These ganglia and their branches form the *sympathetic nervous system* (Figs. 1 and 2), as distinguished from the cerebro-spinal nervous system, consisting of the brain and spinal cord and the nerves proceeding from and to them.*

The Brain, Spinal Cord and their Membranes.—The *brain* lies in the skull and is continuous through the *foramen magnum* (Fig. 20) of the occipital bone with the *spinal cord*, which lies in the vertebral column, and should be considered as a part of the brain. Both the brain and the spinal cord are incompletely separated by grooves and fissures into similar right and left halves. They are very soft and easily crushed,

* The name "sympathetic nervous system" is largely a misnomer, since it is a part of the general nervous system and works in direct connection with it.

and are accordingly placed in almost completely closed bony cavities, and enveloped by membranes which give them support. These membranes are three in number. The external covering, the *dura mater*, is tough, strong, and composed of connective tissue. The innermost membrane in immediate contact with the brain and cord, the *pia mater*, is less dense and tough than the dura mater. A layer of flat cells covers the outside of the pia, and a similar layer lines the inside of the dura; these two layers form the third membrane, the *arachnoid*. In the space between the two layers of the arachnoid is a small quantity of watery *cerebro-spinal liquid*.

The Spinal Cord (Fig. 113) is nearly cylindrical in form, although a little wider laterally than dorso-ventrally, and tapering off at its posterior end. Its

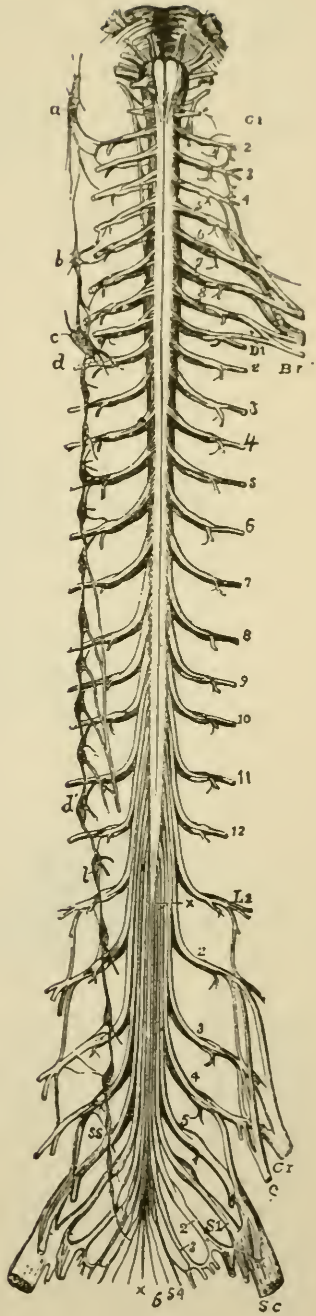

FIG. 113.

FIG. 113.—Diagrammatic view from before of the spinal cord and medulla oblongata, including the roots of the spinal and some of the cranial nerves, and on one side the gangliated chain of the sympathetic. The spinal nerves are enumerated in order on the right side of the figure. *Br*, brachial plexus; *Cr*, anterior crural, *O*, obturator, and *Sc*, great sciatic nerves, coming off from lumbo-sacral plexus; ×, ×, filum terminale; *a*, *b*, *c*, superior, middle, and inferior cervical ganglia of the sympathetic, the last united with the first thoracic, *d*; *d'*, the eleventh thoracic ganglion; *l*, the twelfth thoracic (or first lumbar); below *ss*, the chain of sacral ganglia.

average diameter is about $\frac{3}{4}$ inch and its length 17 inches. It weighs $1\frac{1}{2}$ ounces. There is no marked limit between the spinal cord and the brain, the one passing gradually into the other. In its course the cord presents two expansions, an upper (Fig. 113), the *cervical enlargement*, reaching from the third cervical to the first dorsal vertebræ, and a lower or *lumbar enlargement*, opposite the last dorsal vertebræ.

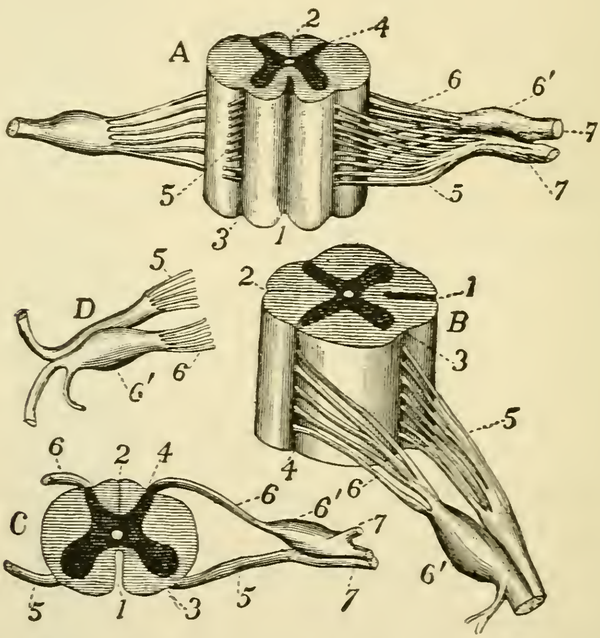

FIG. 114.—Diagrams of spinal cord and nerve roots. *A*, a small portion of the cord seen from the ventral side; *B*, the same seen laterally; *C*, a cross-section of the cord; *D*, the two roots of a spinal nerve; 1, anterior (ventral) fissure; 2, posterior (dorsal) fissure; 3, surface groove along the line of attachment of the anterior nerve roots; 4, line of origin of the posterior roots; 5, anterior root filaments of a spinal nerve; 6, posterior root filaments; 6′, ganglion of the posterior root; 7, 7′, the first two divisions of the nerve trunk after its formation by the union of the two roots.

Running along the middle line on both the ventral and the dorsal aspects of the cord are fissures which (*C*, Fig. 114) nearly divide it into right and left halves.

A transverse section (Fig. 115) shows that the substance of

the cord is not alike throughout, but that its *white* superficial layers envelop a central *gray substance* containing nerve cells

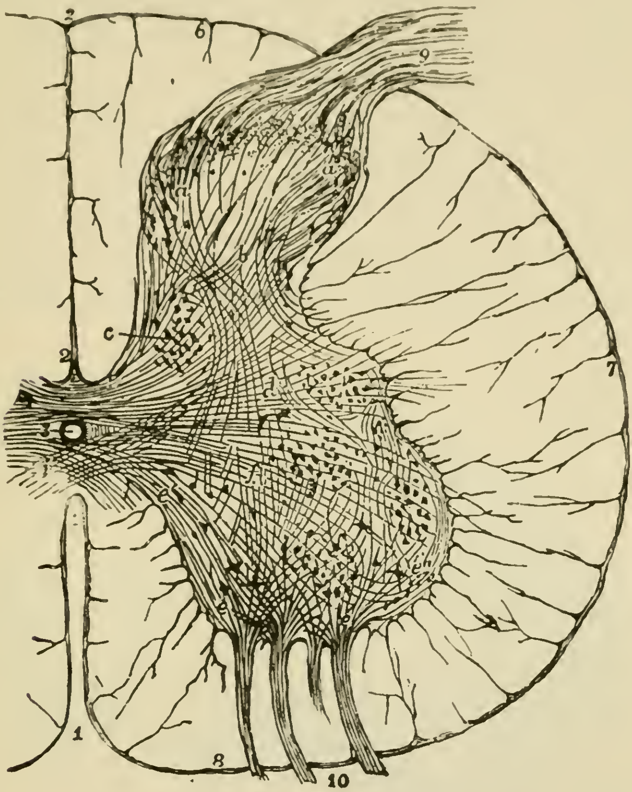

FIG. 115.—A thin transverse section of half the spinal cord magnified about 10 diameters. 1, anterior fissure; 2, posterior fissure; 3, central canal; 8, *pia mater* enveloping the cord; 6, 7, bands of pia mater penetrating the cord and supporting its nerve elements; 9, a posterior root; 10, bundles of an anterior root; *a*, *b*, *c*, *d*, *e*, groups of nerve cells in the gray matter.

arranged somewhat in the form of a capital H. The crescent-shaped halves of the gray matter are turned back to back and united across the middle line by the *gray commissure.*

The white portion of the spinal cord surrounding the central gray matter is composed almost entirely of nerve fibres with their sheaths. These pass up and down the cord in well-defined tracts.

The Spinal Nerves.—Thirty-one pairs of spinal nerves

join the spinal cord in the neural canal of the vertebral column, entering the canal through the intervertebral foramina (Fig. 113). Each divides in the foramen into a dorsal and ventral portion, known respectively as the *posterior* and *anterior roots* of the nerve (6 and 5, Fig. 114), which are attached to the sides of the cord. On each posterior root is a *spinal ganglion* (6′, Fig. 114), placed where it joins the anterior root to make up the *common nerve trunk*. Immediately after its formation by the mixture of fibres from both roots, the trunk begins to divide into branches for the supply of some region of the body.

The Brain (Fig. 116) is far larger than the spinal cord and more complex in structure. It weighs on the average about 50 ounces in the adult. The brain consists of three main

FIG. 116.—Diagram illustrating the general relationships of the parts of the brain. *A*, fore-brain; *b*, mid-brain; *B*, cerebellum; *C*, pons Varolii; *D*, medulla oblongata; *B*, *C*, and *D* together constitute the hind-brain.

masses, each with subsidiary parts, following one another in series from before back, and respectively known as the *fore-*

brain, *mid-brain*, and *hind-brain*.* In man the fore-brain (*A*), weighing about 44 ounces, is much larger than all the rest put together and overlaps them. It is formed chiefly of two large convoluted masses, separated from one another by a deep fissure, and known as the *cerebral hemispheres*. The great size of these is very characteristic of the human brain in contrast to the lower animals. Beneath each cerebral hemisphere is an *olfactory lobe* (*I*, Fig. 118), inconspicuous in man, but in animals often larger than the cerebral hemispheres, as in most fishes. The mid-brain (*b*) forms a connecting isthmus

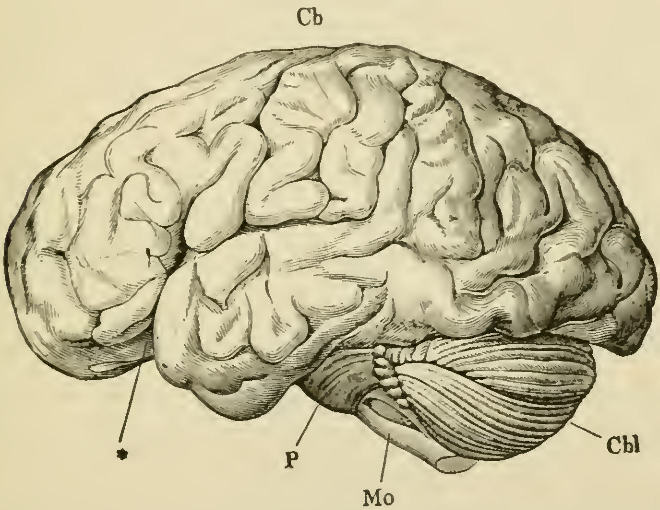

FIG. 117.—The brain from the left side. *Cb*, the cerebral hemispheres forming the main bulk of the fore-brain ; *Col*, the cerebellum ; *Mo*, the medulla oblongata ; *P*, the pons Varolii ; *, the fissure of Sylvius.

between the two other divisions. The hind-brain consists of three main parts ; on its dorsal side the cerebellum (*B*, Fig. 116), on the under side the *pons Varolii* (*C*, Fig. 116), and

* The terms arise from the relative positions of the three hollow nodules in the embryonic central nervous tract, which later develop to form these portions of the adult brain.

behind the *medulla oblongata* (*D*, Fig. 116), which joins the spinal cord.

In nature the main divisions of the brain are not separated as has been represented in the diagram for the sake of clearness, but lie close together with the mid-brain entirely covered on its dorsal side (Fig. 117). Nearly everywhere the surface of the brain is laid in folds, known as the *convolutions*, which are deeper and more numerous in man than in any of the animals.

The brain, like the spinal cord, consists of gray and white nervous matter, but somewhat differently arranged, since in addition to containing gray nerve matter in its interior, a great part of the brain's surface is also covered with it. By the numerous convolutions of the cerebellum and of the cerebral hemispheres, the surface over which this gray substance is spread is very much increased.

The Cranial Nerves.—Twelve pairs of nerves leave the skull cavity by apertures in its base, and are known as the *cranial nerves*. Most of them spring from the under side of the brain, which is represented in Fig. 118. The *first pair*, or *olfactory nerves (I)*, are the nerves of smell; they arise from the under sides of the olfactory lobes and pass out through the roof of the nose. The *second pair*, or *optic nerves (II)*, are the nerves of sight; they spring from the mid-brain, and, under the name of *optic tracts*, run down to the under side of the fore-brain, where they unite to form the *optic commissure*, from which an *optic nerve* proceeds to each eyeball.

All the remaining cranial nerves arise from the hind-brain. The *third pair*, or *motor nerves of the eye (III)*, are distributed to three of the muscles which move the eyeball, and also to the muscle which lifts the upper eyelid.

The *fourth pair (IV)* are quite small; each goes to one muscle of the eyeball.

The *fifth pair* or *trigeminals* (*V*) resemble the spinal nerves in having two roots, one of which possesses a ganglion (the *Gasserian ganglion*). Beyond the ganglion the two roots

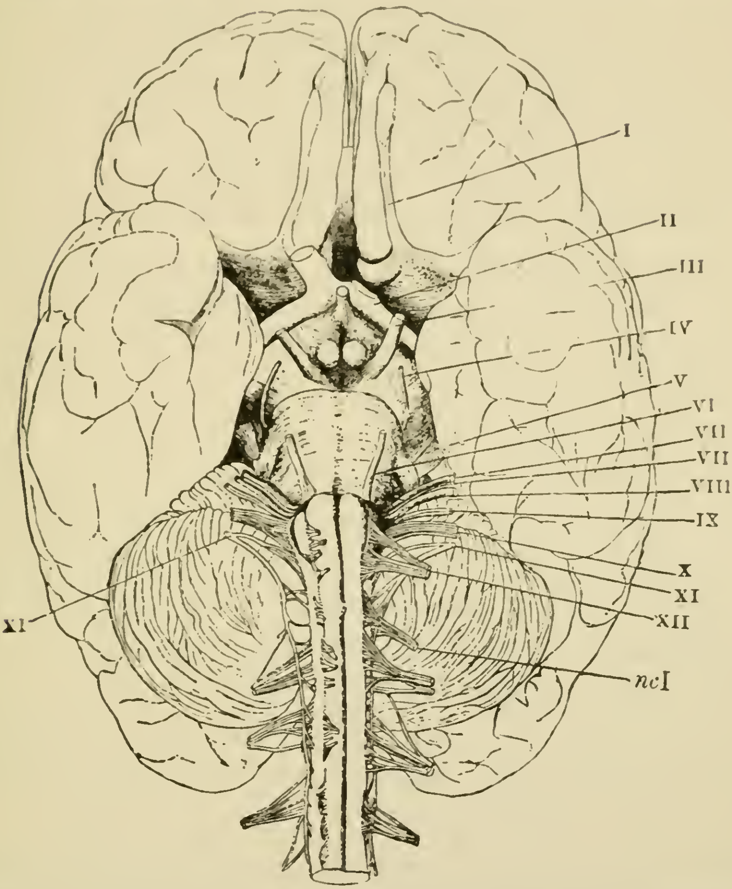

FIG. 118.—The base of the brain. The cerebral hemispheres are seen overlapping all the rest. *I*, olfactory lobes ; *II*, optic tract passing to the optic commissure from which the optic nerves proceed ; *III*, the third nerve or *motor oculi ; IV*, the fourth nerve or *patheticus ; V*, the fifth nerve or *trigeminalis ; VI*, the sixth nerve or *abducens ; VII*, the seventh or facial nerve or *portio dura ; VIII*, the auditory nerve or *portio mollis ; IX*, the ninth or glosso-pharyngeal ; *X*, the tenth or pneumogastric or *vagus ; XI*, the spinal accessory ; *XII*, the hypoglossal ; *ncI*, the first cervical spinal nerve.

form a common trunk which divides into three main branches. The first of these, the *ophthalmic*, is distributed to the muscles and skin over the forehead and upper eyelid, and also gives branches to the mucous membrane lining the nose, and to the

integument over that organ. The second division, the *superior maxillary nerve*, gives branches to the skin over the temple, to the cheek between the eyebrow and the angle of the mouth, to the upper teeth, and to the mucous membrane of the nose, pharynx, soft palate and roof of the mouth. The third division, the *inferior maxillary*, is the largest branch of the trigeminal. It is distributed to the side of the head, the external ear, the lower lip, the lower part of the face, the mucous membrane of the mouth, the anterior two thirds of the tongue, the lower teeth, the salivary glands, and the muscles which move the lower jaw in mastication.

The *sixth pair (VI)* are distributed each to one muscle of the eyeball on its own side.

The *seventh pair*, or *facial nerves (VII)*, are distributed to most of the muscles of the face and scalp.

The *eighth pair*, or *auditory nerves (VIII)*, are the nerves of hearing, and are distributed to the inner part of the ear.

The *ninth pair*, or *glosso-pharyngeal nerves (IX)*, are distributed chiefly to tongue and pharynx.

The *tenth pair*, *pneumogastric nerves* or *vagi (X)*, give branches to the pharynx, gullet, stomach, larynx, windpipe, lungs, and heart. The vagi run farther through the body than any other cranial nerves.

The *eleventh pair*, or *spinal accessory nerves (XI)*, do not arise mainly from the brain, but from the spinal cord by a number of roots attached to its upper portion, between the anterior and posterior roots of the proper spinal nerves. Each enters the skull cavity alongside of the spinal cord, gets a few filaments from the medulla oblongata, and passes out by the same aperture as the glosso-pharyngeal and pneumogastric nerves. Outside the skull the spinal accessory divides into two branches, one of which joins the pneumogastric

trunk, while the other is distributed to muscles about the shoulders.

The *twelfth pair*, or *hypoglossal nerves (XII)*, are distributed mainly to the muscles of the tongue.

The Sympathetic Nervous System.—The ganglia which form the main centres of the sympathetic nervous system lie in two rows (Fig. 113), one on each side of the bodies of the vertebræ. Each ganglion is united by a nerve trunk with the one anterior and the one posterior to it. Two chains are thus formed reaching from the base of the skull to the coccyx and lying in the ventral cavity (Fig. 2).

Each ganglion is united by short branches to neighboring spinal nerves, and near the skull to various cranial nerves also. From the ganglia and their uniting cords arise numerous trunks, forming networks in the thorax and abdomen, from which nerves are given off to the organs situated in those cavities. Many sympathetic nerves finally end in the walls of the blood vessels of various organs. To the naked eye they are commonly grayer in color than the cerebro-spinal nerves.

By means of the junctions between the cranial and spinal nerves and the sympathetic system, the brain controls the parts supplied by this system.

Nerve Tissue.—The microscope shows that the nervous organs contain structures peculiar to themselves, known as *nerve fibres* and *nerve cells*. The cells are found only in the brain, cord and ganglia, whereas the fibres, of which there are two main varieties known as the *white* and the *gray*, are found throughout the nervous system. The white variety predominates in the cerebro-spinal nerves and in the white substance of the brain and cord; the gray, in the sympathetic trunks and the gray portions of the brain and cord.

White Nerve Fibres consist of extremely delicate threads, about $\frac{1}{2000}$ inch in diameter, but frequently of a length proportionally very great. If a perfectly fresh white nerve fibre is examined with the microscope it presents the appearance of a homogeneous glassy thread. Soon, however, it acquires a characteristic double border (Fig. 119), from the coagula-

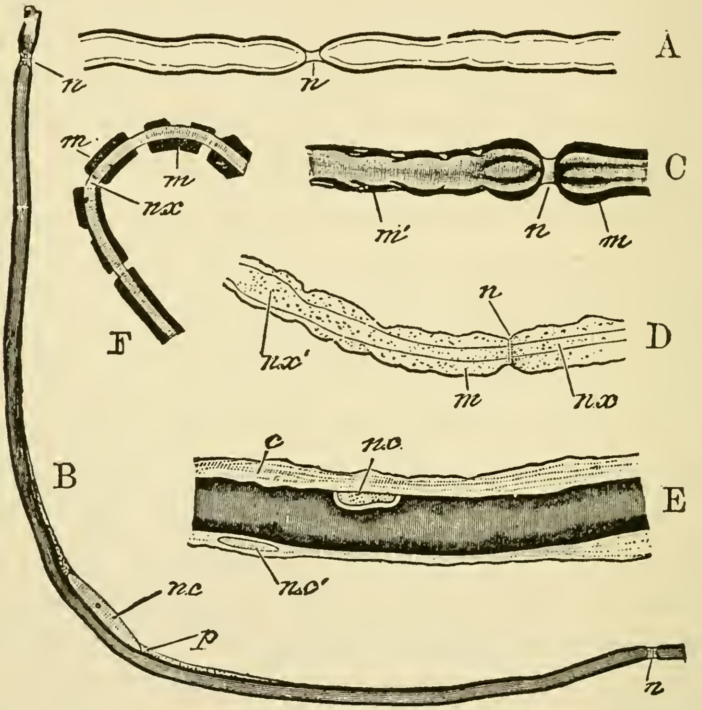

FIG. 119.—To illustrate the structure of nerve fibres. *A*, nerve fibre examined fresh: *n*, node. *B*, nerve fibre with axis cylinder shaded, and medulla represented by dark lines: *n.c*, nucleus; *p*, granular cell substance near the nucleus. *C*, more highly magnified: *m*, medulla; *n*, node. *D*, nerve treated with reagents to show the axis cylinder: *n.x*, surrounded by medulla, *m*. *E*, nerve treated with reagents to show *n.c.* nucleus with fine line over it representing the neurilemma, and outside this fine connective tissue, *c*: *n.c'*, nucleus lying in the fine connective tissue. *F*, nerve fibre deprived of its neurilemma showing medulla broken up into fragments, *m*, surrounding the axis cylinder, *n x*.

tion of a portion of its substance, as a result of which three layers are brought into view. Outside is a thin transparent envelope called the *primitive sheath* or *neurilemma;* inside

this is a fatty substance, forming the *medullary sheath* (the coagulation of which gives the fibre its double border); in the centre is a core, the *axis cylinder*, which is the essential part of the fibre, since near its ending the primitive and medullary sheaths are frequently absent. At intervals of about $\frac{1}{25}$ inch along the fibre are found *nuclei*. In the course of a nerve trunk its fibres rarely divide; when a branch is given off some fibres merely separate from the rest, much as a skein of silk might be separated at one end into smaller bundles containing fewer threads. The white matter of the spinal cord, brain, and nerve trunks consists largely of medullated nerve fibres, whereas the gray matter of the cord and brain consists largely of nerve cells.

Gray Nerve Fibres have no medullary sheath, and consist merely of an axis cylinder and primitive sheath. Gray fibres are especially abundant in the sympathetic trunks, and are the only ones found in the olfactory nerve.

Nerve Cells.—In the ganglia lying in the course of nerves and in the gray matter of the spinal cord and the brain are found large nucleated and branched cells connected with the nerve fibres, and called *ganglion* or *nerve cells*. They differ in size, shape, and number of branches, but present fairly characteristic appearances.

The cell substance is granular and contains a large, round nucleus with a central spot called the nucleolus. There are usually several branches which subdivide to form tree-like forms. One branch, however, does not divide, but forms the nerve fibre, *axis cylinder* or *neuron*, which finds its way out to other parts of the nervous system.

It was formerly supposed that the nerve cells were connected with each other by means of their branches and axis cylinders, but it has recently been shown that each nerve cell

with its branches and axis cylinder forms an anatomical unit and that the nutrition of the branches and axis cylinder depends entirely upon their connection with the nerve cell.

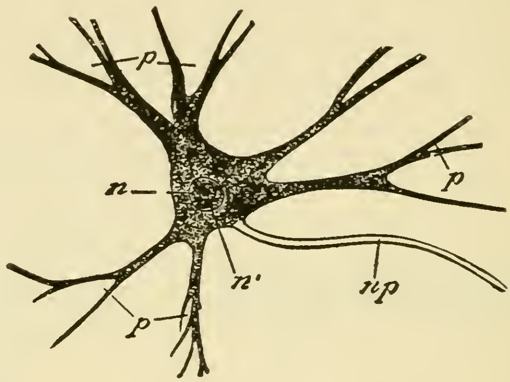

Fig. 120.—A large nerve cell from the anterior horn of the spinal cord. *n*, nucleus; *n'*, small body, called the nucleolus, inside the nucleus ; *p*, branched processes ; *n.p*, unbranched process continued into the axis cylinder of a motor nerve fibre.

If the nerve fibre becomes injured, the end of the fibre beyond the point of injury dies and is replaced by a new fibre which grows out from the cell.

The Structure of Nerve Centres.—The nerve cells represent the active part of the nervous tissue. Since they are grouped in special localities of the body, such as the ganglia, spinal cord and brain, these are called *nerve centres*. This is especially true of the brain and spinal cord, which constitute the *central nervous system*. The nerve centres consist of white and gray nerve fibres, of nerve cells, and of connective tissue and blood vessels, arranged together in different ways in different centres.

CHAPTER XX.

THE GENERAL PHYSIOLOGY OF THE NERVOUS SYSTEM.

Nature of Nervous Impulse.—A nervous impulse has so little direct manifestation that it has been impossible to determine its true nature. It shows itself mainly in muscular contraction, glandular activity, etc. It is transmitted with such great rapidity through the nerves (one hundred feet per second) that it is difficult to suppose that it is a mechanical or chemical process; at the same time it is so much slower than an electric current that it is probably not at all related to it. It is thought to be a molecular change of some kind passed along the axis cylinder.

If a nerve is cut, and an electric current is sent through it, the contraction of the muscle attached to it shows that a nervous impulse has passed along the nerve. If a drop of acid or of a strong salt solution is placed on the end of the nerve, the same result is reached. Under natural conditions, however, nervous impulses do not arise in nerve fibres, but in nerve cells or in special structures connected with the ends of nerves, as the sense organs. Experiments have shown that a nerve fibre merely conducts the nervous impulse, but has no share in its formation or modification.

The strength of the nervous impulse judged from a mechanical standpoint is infinitely less than the energy which is discharged in muscle or gland as a result of its action; it bears

very much the relation to the muscular energy which the force required to pull the trigger of a gun bears to that developed by the explosion of the powder. The discovery that nerve cells are not continuous with each other by means of their fibres, but that each cell and its branches, including the axis cylinder, forms a distinct unit, complicates the problem of the real nature of the nervous impulse. Anatomically the path from the skin through the nerve trunks to the spinal cord and thence up to the cortex of the brain is made up of a number of these units. The impulse which travels from the end of the finger to the cortex of the brain to excite consciousness must either leap from one unit to another in this chain in order to bring its message to consciousness, or the nervous impulse of one cell must when transmitted along its axis cylinder (neuron) be able to stimulate the next cell to discharge a similar impulse along its neuron until the final stage is reached and a change in consciousness produced. If the latter supposition is true, the cells act as relays, and we have what may be called a relay system.

Nerve Action.—When the large nerve trunk which passes down the thigh is cut across, an animal loses the power of movement in the muscles of the leg. It is also unconscious of pinching or pricking of the skin of the leg; in fact, it is possible to mutilate its leg to any extent without giving rise to pain. If, however, the distal end of the cut nerve is pinched or an electric shock is sent through it, the muscles contract. If the proximal end of the cut nerve is pinched or an electric shock is sent through it, the animal shows signs of pain.

The nerve trunks transmit to muscles stimuli which cause them to contract (motor stimuli).

Sensations do not lie in the exterior parts of the body.

Nerve trunks transmit stimuli which give rise to sensation, as, for example, sensations of pain (sensory stimuli).

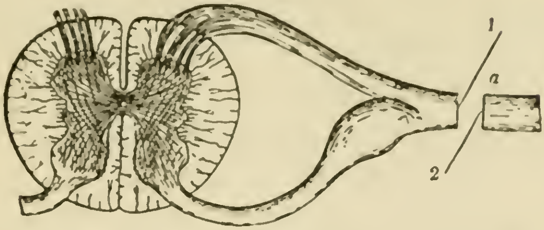

FIG. 121.—Illustrating the functions of the spinal nerves. *Divided at a.*—Irritated at 1: pain. Irritated at 2: muscular contraction.

When the anterior nerve roots of spinal nerves are cut, all power of motion is lost in the muscles with which they are connected. In this case, however, the animal feels perfectly

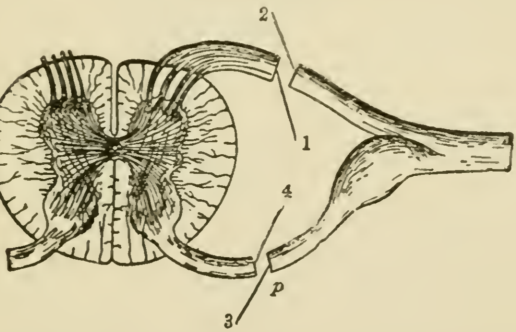

FIG. 122.—Illustrating the functions of the roots of the spinal nerves. *a*, anterior root; *p*, posterior root *Divided at a.*—Irritated at 1: no result. Irritated at 2: contraction of muscles supplied with fibres from the root. *Divided at p.*—Irritated at 3: no result. Irritated at 4: pain produced.

the stimulation of the skin to which the nerve trunks are distributed. If the distal ends of these nerves are stimulated electrically, it causes contraction of the muscles. When the proximal ends are stimulated electrically, there is no effect.

The nerves which transmit the motor stimuli pass through the anterior roots of the spinal nerves.

Motor nerves carry stimuli outward from the central part of the nervous system (efferent nerves).

When the posterior roots are cut and the anterior are intact, the power of motion in the limb is not affected, but all sensation is lost. If the distal ends are stimulated electrically or pinched there is no effect, but when the proximal ends are stimulated pain is manifested.

The nerves which transmit the sensory stimuli pass through the posterior roots of the spinal nerves.

Sensory nerves carry stimuli from the outside of the body toward the central part of the nervous system (afferent nerves).

It has also been found that when an animal has been tired out, as a bird by flying, the nerve cells in the anterior part of the gray matter of the cord, with which the nerves of the fatigued muscles are connected, show distinct changes in their microscopic structure. These changes have been interpreted to mean fatigue of the nerve cells. When these cells are destroyed, the power of motion is lost in the connected muscles.

The motor nerve cells which cause the contractions of the muscles with which they are connected by nerves lie in the anterior cornua of the spinal cord.

When the ganglia of the dorsal roots of the spinal nerves are destroyed, sensation is lost in the parts connected by fibres with the cells lying in the destroyed region.

Sensory cells lie in the ganglia of the dorsal roots of the spinal nerves.

When the upper part of the spinal cord is injured, all sensation and voluntary motion are lost in the legs and lower trunk; the individual becomes unconscious of the entire lower part of his body. If the sole of the foot is then tickled with a feather or quill, or a hot object applied to it, the foot is jerked away by the muscles of the leg, showing that the power of motion is in itself intact.

The motor nerve cells of the cord are not capable of starting

voluntary contractions, but depend upon stimuli from other cells.

They may be stimulated by strong sensory stimuli from the periphery to produce protective movements (reflex action).

The seat of sensation does not lie in the spinal cord.

When the gray matter in certain localities of the cortex of the brain is removed, power of voluntary motion is lost for certain muscles. When the nerve cells lying in the same

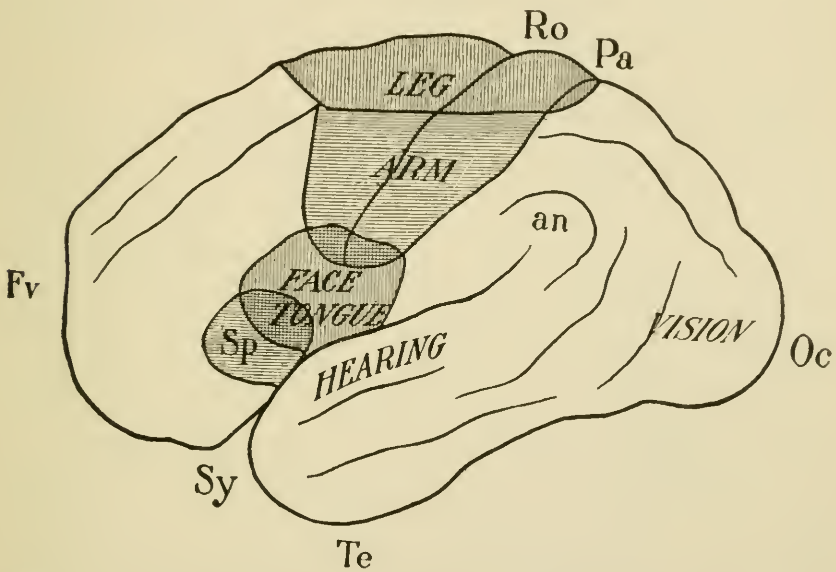

FIG. 123.—Diagram of outer surface of left cerebral hemisphere to illustrate the localization of functions. The motor area is shaded in vertical and transverse lines: *Sy*, fissure of Sylvius; *an*, angular gyrus or convolution; *Ro*, fissure of Rolando; *Fv*, frontal lobe; *Pa*, parietal lobe; *Te*, temporal lobe. Only a very few of the more important fissures are indicated.

localities of the brain are stimulated, muscular movements are caused in the group of muscles that was paralyzed by the removal of the cells. The removal of cortical gray matter near the fissure of Rolando (Fig. 123) in the left side of the brain, for example, gives rise to paralysis of the right leg muscles; the stimulation of cells in the same region causes contraction of the same muscles.

The motor cells which cause voluntary muscular movements are seated in the cortex of the brain.

Definite areas of the brain correspond to certain muscular groups, as leg, arm, and tongue (localization of functions).

*The motor areas of each side of the brain correspond with muscular groups upon the opposite side of the body.**

Afferent Nerves.—All sensory nerves are afferent nerves, but not all afferent nerves are sensory, since many nerves bring impulses inward to the central nervous system which do not result in sensation ; among these are the afferent nerves from the heart, muscles, and viscera.

Efferent Nerves.—Motor nerve impulses have their most tangible manifestations in muscular contractions *(musculo-motor)*, but these do not constitute the most important of the outgoing stimuli transmitted by the efferent nerves, since they are also concerned in controlling the heart *(cardio-motor)*, the secretion of glands *(secreto-motor)*, intestinal movements *(viscero-motor)*, changes in blood vessels *(vaso-motor)*, and cellular activity in general *(trophic †)*.

In addition, efferent nerves have a distinctly different function. The vagus, for example, tends to retard or *inhibit* the action of the heart, and the vaso-dilator nerves are supposed to diminish the stimulation of the vaso-constrictors when they cause a dilatation of blood vessels. This action is called *inhibition*, and the nerves, *inhibitory nerves.* Since these inhibitory results are due to nervous stimuli sent out from the

* This is true in general, but it is claimed that either side of the brain can control both sides of the body, though it does not have to do so under normal conditions.

† Trophic nerves are those which are supposed to stimulate nutritive changes in the cell itself, that is, to bring about in the cell those changes which keep it in good working order. The existence of such nerves has not been demonstrated, but is inferred.

central nervous system, the nerves which carry them are efferent nerves.

Relation between Sensation and Motion.—When a hot iron is applied to the skin, muscles contract so as to remove the threatened part from danger. As we have seen, this takes place even when the spinal cord is injured, provided that the point of injury is above the place where lie the sensory and

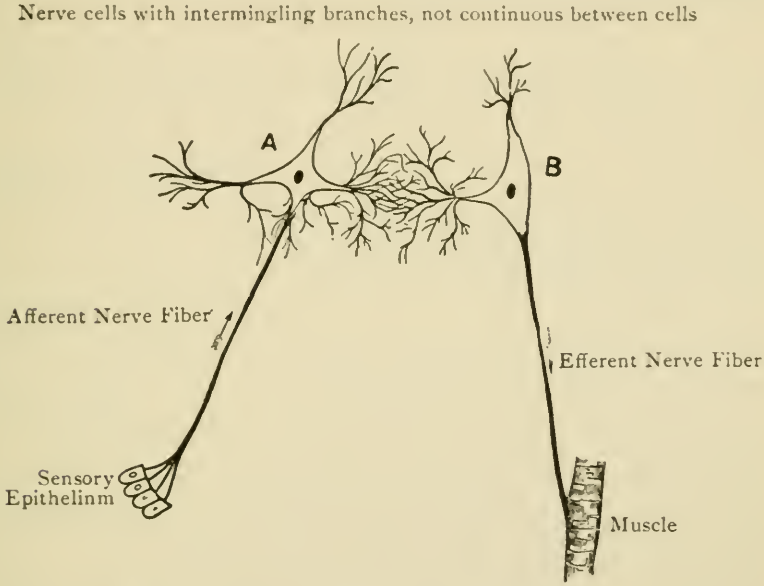

FIG. 124.—Diagram of reflex arc. (After Colton.)

motor cells directly concerned. This movement is very quick, taking only .06 to .08 Sec. Experiments have shown conclusively that the nerve cells (sensory and motor) concerned in this action are located in the gray matter of the cord. Since the motion immediately follows the stimulation without the intervention of consciousness, it is said to be "reflected" and the process is called a *spinal reflex*.

If the irritation of the skin is so slight that it does not give rise to a reflex withdrawal, it may excite consciousness and

the consequent desire for withdrawal on the part of the individual. Under these circumstances the least time required for the movement is much greater, averaging .15 Sec., since the impulse has to be transmitted to the brain and a much greater number of cells have to act. This process is known as a *voluntary reaction.*

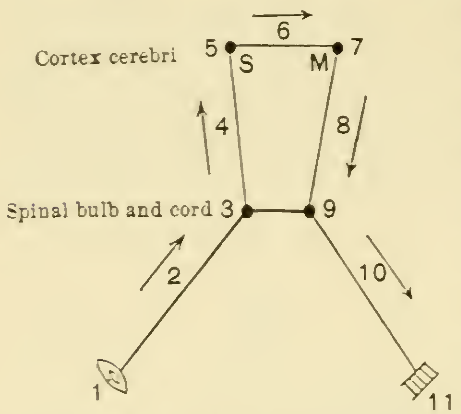

FIG. 125.—Voluntary reaction. 1, epithelium; 2. afferent nerve fibre; 3, spinal sensory cell; 4. afferent tract; 5. cortial sensory cell; 6. commissural fibre; 7, cortical motor cell; 8, efferent tract; 9. spinal motor cell; 10, efferent nerve fibre; 11, muscle.

Functions of the Spinal Cord.—We have seen that the spinal cord contains (1) cells which have the power of producing muscular contractions, (2) cells which receive sensory impulses from the nerve endings, as in the skin, and (3) nerve fibres which connect these cells with the periphery and with other cells in the upper part of the spinal cord and the brain. Many experiments on animals with the spinal cord intact but with the brain destroyed show that they are able to make complicated reflex movements which are in general of a protective nature. As we study the normal individual we see that many of the sudden movements made are of the nature of the spinal reflex, since they are done so quickly that the individual cannot inhibit them, as winking. We thus see that the cord acts (1) as a motor centre, either in response to stimulation from cells in the brain, or, reflexly, in response to sensory stimuli in the periphery, and (2) as a conductor of nervous impulses from the periphery to the brain, and the reverse.

The motor and sensory fibres which pass up the cord to

the brain cross from one side to the other. Thus the right side of the body is in general controlled by the left side of the brain and *vice versa*. The sensory fibres cross shortly after entering the cord in the dorsal root. The motor fibres cross mainly in the upper part of the cord, where they may be recognized as interlacing bundles. These motor and sensory fibres find their way through the length of the spinal cord in fairly well defined columns or tracts outside of the gray matter.

Functions of the Spinal Bulb (Medulla Oblongata).—The spinal cord at its upper part, just before its union with the brain, expands and opens out, exposing the gray matter on its dorsal side. This expansion of the cord is called the *spinal bulb* or *medulla oblongata*. Experiments have shown that nerve cells in the spinal bulb include among others those which have direct control of the heart beat and of respiration. These centres have been described as automatic, but it is probably not true that they are automatic in the sense that they initiate the muscular contractions of the heart or respiratory muscles without any stimulus coming to them. They are doubtless reflex centres and are stimulated from without, probably by the condition of the blood. When the spinal bulb is injured death results from the cessation of the heart action and of breathing. Hence it is one of the vital centres of the nervous system.

Functions of the Ganglia of the Brain.—In the base of the brain, covered over by the cerebral hemispheres, lie isolated patches of gray matter known as the basal *ganglia*. The functions of these are not well understood since experimental evidence is more or less contradictory, owing to the difficulty of performing experiments without injuring adjacent nerve fibres.

Functions of the Cerebrum.—When the cerebral hemispheres of a pigeon are destroyed and the rest of the body is in a normal condition, the animal can still control its muscles so as to execute many movements, but gives no sign of consciousness. Left to itself it will stand still until it dies; corn and drink placed before it arouse in it no idea of eating; it will die of starvation surrounded by food. Yet it can move all of its muscles, and if food is placed in its mouth will swallow it. If its tail is pulled it will walk forward; if it is put on its back it will get on its feet; if it is thrown into the air it will fly until it strikes against something on which it can alight; if its feathers are ruffled it will smooth them with its bill.

The difference between a pigeon in this state and an uninjured pigeon lies in the absence of the power of forming ideas or of initiating movements. It has no thoughts, no ideas, no will. We cannot predict what an uninjured pigeon will do under varying conditions; we can predict what the pigeon with no cerebral hemispheres will do; it is a mere machine or instrument, which can be played upon. In such a pigeon the excitation of any given sensory nerve excites reflexly the nerve centres of the spinal cord and brain, which cause certain muscles to contract, resulting in the same invariable movement. The pigeon exhibits no evidence of possessing consciousness; it has no desires or emotions; it stays quiet while left to itself, and reacts reflexly when any stimulus is given to it, and always in an unvarying manner.

In human beings, accidental injury to parts of the brain and disease have made it possible to study the associated losses of power. This evidence confirms the inferences based upon experiments on the lower animals, and shows that in the

human brain the functions are distributed in much the same way as in dogs and pigeons. All actions directed by voluntary attention thus find their origin in the nerve cells of the cerebrum.

Brain Localization.—As we have seen, certain portions of the cortex of the cerebrum are associated with definite movements of the limbs, etc. These motor areas have been mapped out with so great clearness that in a number of cases of paralysis due to brain tumor the surgeon has confidently cut into the brain in a definite spot and located the trouble. Experiments show, however, that the movements which are caused by stimulation of the cells in these areas are complex movements, such as scratching or picking up objects, involving a large number of muscles which are definitely controlled to accomplish a certain end.

Since the motor cells in the spinal cord act upon single fibres of muscles, there are doubtless intermediate motor centres standing between the cells of the cortex of the brain and the immediate motor cells of the cord which have the power of controlling large numbers of spinal motor cells and unifying their work.

This mechanism is somewhat similar to that existing in a factory. The individual workmen correspond to the spinal motor cells; the foremen who oversee the work of these men correspond to the intermediate cells; and the superintendent who has charge of the foremen, and hence of the whole establishment, corresponds to the cells of the brain.

The centres of the brain associated with the sense organs, as seeing and hearing, are pretty definitely localized, but those which have to do with intellectual processes, as memory, reasoning, and association, have not been definitely localized. Doubtless they have no definite localization, since

each process probably involves one phase of the activity of many groups of brain cells.

Intercentral Fibres.—It is easy to see that the various processes which thus call into play large numbers of brain cells necessitate nerve fibres to connect the cells of different parts of the cortex. These fibres are called *intercentral* or *commissural* fibres and take their paths between the brain cells, without passing out of the cranium.

Functions of the Cerebellum.—When the cerebellum is removed from animals they stand and walk unsteadily, staggering and fluttering with many useless movements. The muscles tend to contract in a less purposeful way and with less vigor. The manifestations permit little of definite inference except this, that the cerebellum is concerned to some degree with the co-ordination of muscular contractions. It is a large organ, and it is to be inferred that it has important functions; their definite values, however, are not yet well determined.

Modes of Nervous Reaction.—The simplest mode of reaction is a spinal reflex, such as the instant withdrawal of the hand upon coming into contact with a hot stove. The response is immediate, always the same, preceded by no conception of the movement to be made and by no conscious memory of the means of making it. The sensory stimuli pass up the afferent nerve to the sensory cells, which in turn influence other cells until finally certain motor cells are selected and stimulated to send impulses down the efferent nerves which result in a complicated but co-ordinated contraction of a number of muscles, producing a protective movement. A voluntary reaction is more complicated. When a bright ball is held before a child, the light waves enter the eye, are translated in the retina into nervous impulses which travel along the afferent nerves to the optic sensory centre of the brain.

The cells of this centre communicate with appropriate centres through intercentral tracts and a desire for the ball results. Motor centres are then stimulated, beginning probably with the arm group of the cortex and ending with the motor cells in the spinal cord. These latter cells, thus selected and unified in their action by the higher motor centres, stimulate the muscle fibres to produce by their contractions the definite movements which give possession of the ball. This mode of action cannot be predicted, involves consciousness, and may even permit considerable delay between the stimulation and the response, as in the case of one whose desire to visit Europe, aroused by books of travel, finds motor completion only after the lapse of years.

The line between reflex and voluntary reaction cannot be sharply drawn in ordinary activity. Voluntary reactions tend through constant repetition to have reflex characteristics in that the motor response follows directly upon the sensory stimuli, as in walking. The cells, at first directed by consciousness, have become trained to do their work without its supervision, but doubtless the same motor cells are involved as in a corresponding voluntary reaction.

The Use of Reflex Centres is to relieve the thinking centres of the vast amount of work which would be thrown upon them if every action of the body had to be planned and willed at each moment. Were not the unconscious regulating nerve centres always at work the mind would be overburdened by the mass of business which it would have to look after. No time would be left for intellectual development if we had to think about and to *will* each heart beat, each inspiration and expiration, and the swallowing of each mouthful of food. Sleep would be impossible, and life as we know it could not be maintained.

Habits.—Every time a nerve cell acts in a given way, it becomes easier for it to repeat the action; as a result many actions which are at first performed only with trouble and thought are executed easily and unconsciously. The act of walking is a good instance; each of us in infancy learned to walk with much pains and care, thinking about each step. But the more we walked the more the nervous system became trained to adapt the muscular movement to the guidance of the nerve impulses from the sole of the foot. At last the contact of the foot with the ground, stimulating some sensory nerves, acts so readily on the "nerve centres of walking" that consciousness need take no heed about it: we walk ahead while thinking of something else. Other instances will readily come to mind, as the difficulty with which we learned to ride, swim, or skate, when obliged to think about and will each movement, and the ease with which we do all these after a little practice. The trained nerve centres then do all the co-ordinating work and consciousness has no more need to trouble about the matter. A habit simply means that the unconscious parts of the nervous system have been trained to do certain things under given conditions.

We thus find, in the tendency of the nervous system to go on doing what it has been trained to do, a physiological reason for endeavoring to form good and to avoid bad habits of every sort. Every thought, every action, leaves in the nervous system its result for good or ill. The more often we yield to temptation the stronger the effort required to resist it, whereas every resistance of temptation helps to make subsequent resistance easier.

Growth of the Brain.—The nervous system in the human being grows more slowly than any other part of the body, for while the nerve cells are complete in number in childhood,

yet their branches and consequently their means of communicating with other cells are not fully developed until much later, even as late as the twenty-fifth or thirtieth year of life. As we have seen, the power of the nervous system to coordinate the activities of the body depends very largely upon the number and extent of these branches. In this lies, in part, the explanation of the slowness with which the mental power of the child develops and the fact that ripe judgment, which is the final test of nerve action, is found only in the mature man or woman. Much of the precocity which is not rare in childhood is due simply to an exceptional memory, and does not mean real intellectual force.

Hygiene of the Brain.—The brain, like the muscles, is improved and strengthened by exercise and injured by overwork or idleness. A man may especially develop one set of intellectual faculties and leave the rest to lie fallow until, at last, he almost loses the power of using them at all. The fierceness of the battle of life especially tends to produce a one-sided mental development. The business man, for example, becomes only too frequently so absorbed in money-getting that he loses the intellectual joys of art, science, and literature, and becomes a mere money-making machine. The scientific man has often no appreciation of art or literature, and the literary man is utterly incapable of sympathy with science. A good collegiate education in early life, on a broad basis of mathematics, literature, and natural science, is the best security against such deformed mental growth.

Besides exercise, the greatest need for the healthy development of the brain is sufficient sleep. The infant sleeps 15 to 20 hours, the young child 12 to 14, and the boy of high-school age should get 9 to 10 hours of sleep. Those who are using the brain require more sleep than those who

are doing muscular work, and no student can safely sleep less than nine hours.

In order that the brain may keep in its best working order, it must work with ease and pleasure. Probably no condition is so important in keeping the nervous system in a healthy state as enjoyment of work and cheerfulness in daily life. Plays and games which give the keenest enjoyment, especially if involving physical activity, are of the utmost importance for the well-being of this master tissue of the body.

CHAPTER XXI.

THE SENSES.

Common Sensation and Special Senses.—Changes in many parts of our bodies are accompanied or followed by states of consciousness which we call *sensations*. All such parts (*sensitive parts*) are in connection, direct or indirect, with the brain by sensory nerve fibres. Since all feeling is lost in any region of the body when this connecting path is severed, it is clear that all sensations, whatever their primary exciting cause, are finally dependent on conditions of the brain. Since all nerves lie within the body as circumscribed by the skin, one might be inclined to suppose that the cause of all sensations would appear to be within our bodies themselves; that the *thing felt* would be recognized as a modification of some portion of the *person feeling*. This is the case with regard to many sensations: headache, toothache, or earache gives us no idea of any external object; it merely suggests to each one a particular state of a sensitive portion of himself. As regards many sensations this is not so; they suggest external causes, and we ascribe the sensations to the external objects as their properties. Thus they lead us to the conception of an external universe in which we live. A knife laid on the skin produces changes in the skin which lead us to think that we feel a cold heavy hard thing which is not the skin. We have, however, no sensory nerves going into the knife and informing us directly of its

condition; what we really feel are the modifications of the body produced by the knife, although we irresistibly think of them as properties of the knife. If, however, the knife cuts through the skin, we cease to feel the *knife* and experience *pain*, which we think of as a condition of ourselves. We do not say the knife is painful, but that the finger is, and yet we have, so far as sensation goes, as much reason to call the knife painful as cold. Applied one way it produced local changes in the skin arousing a sensation of cold, and in another local changes causing a sensation of pain. Nevertheless in the one case we speak of the cold as being in the knife, and in the other of the pain as being in the finger.

Those sensitive parts, such as the surface of the skin, through which we get information about the outer world are of far more intellectual value to us than such parts, as the subcutaneous tissue, which give us sensations referred only to conditions of our own bodies. The former are called *organs of special sense;* the latter possess *common sensation.*

Common Sensations are numerous, as, for example, pain, hunger, nausea, thirst, satiety, and fatigue.

Hunger and Thirst regulate the taking of food. Local conditions play a part in their production, but general states of the body are also concerned.

Hunger in its first stages is due to a condition of the gastric mucous membrane which comes on when the stomach has been empty some time. It may be temporarily stilled by filling the stomach with indigestible substances, but soon the feeling comes back intensified and can be allayed only by the ingestion of nutritive materials. Provided that these are absorbed and reach the blood their mode of entry is not essential; hunger may be stayed by injections of food into the intestine as completely as by filling the stomach with it.

Similarly, thirst may be temporarily relieved by moistening the throat without swallowing, but soon returns; whereas it may be permanently relieved by water injections into the veins, without wetting the throat at all.

Both sensations depend in part on local conditions of sensory nerves, but especially on the poverty of the blood in foods or water, which leads to changes in nerve cells. It has even been inferred that there are hunger and thirst centres of the brain which are thus stimulated.

The Special Senses are commonly described as five in number, sight, hearing, touch, smell, and taste, but to these we must add several others.

The Visual Apparatus consists of nervous tissues immediately concerned in giving rise to sensations, supported, protected, and nourished by other parts. Its essential parts are (1) *the retina*, a thin membrane lying in the eyeball and containing microscopic elements which are so acted upon by light as to stimulate (2) *the optic nerve;* this nerve ends in (3) the *visual centre* of the brain, which when stimulated arouses in our consciousness a feeling or *sensation of sight.* The visual centre may be excited in very many ways, and quite independently of the optic nerve or of the retina, as is frequently seen in delirious persons, in whom inflammation or congestion of the brain excites directly the visual centre and gives rise to visual hallucinations.

Usually, however, the cerebral visual centre is excited only through the optic nerve, and the optic nerve only by light acting upon the retina. The eyeball, containing the retina, is so constructed that light can enter it, and so placed and protected in the body that as a general thing no other form of energy can act upon it so as to stimulate the retina. Under exceptional circumstances we may have sight sensa-

tions when no light reaches the eye. Anything which stimulates the retina, so long as it is connected by the optic nerve with the cerebral visual centre, will cause a sight sensation. A severe blow on the eye, even in complete darkness, will cause the sensation of a flash of light ; the compression of the eyeball excites the retina, the retina excites the optic nerve, the optic nerve the visual nerve centre, and the result is a sight sensation.*

The Eye Socket.—The eyeball is lodged in a bony cavity *the orbit*, open in front. Each orbit is a pyramidal chamber containing connective tissue, blood vessels, nerves, and much fat. The fat forms a soft cushion on which the back of the eyeball rolls.

The Eyelids are folds of skin, strengthened by cartilage

* The fact that sight sensations may be aroused quite independently of all light acting upon the eye is paralleled by similar phenomena in regard to other senses, and is of fundamental psychological and metaphysical importance. That a blow on the closed eye gives rise to a vivid light sensation, even in the absence of all actual light, proves that our sensation of light is quite a different thing from light itself. The visual sensory apparatus, it is true, is so constructed and protected that of all the forces of nature, light is the one which far more frequently stimulates it. But as regards the peculiarity in the quality of the sensation which leads us to classify it as " a visual sensation," that peculiarity has nothing to do with any property of light. The visual nerve centre when stimulated causes a sight sensation, whether it has been excited by light, by a blow, or by electricity. Similarly the auditory brain centre gives us a sound sensation when stimulated by actual external sound waves, by a blow on the ear, or by disease of the auditory organ. One kind of energy, *light*, excites more often than any other the visual nerve apparatus; another, *sound*, the auditory nerve apparatus; a third, *pressure*, the touch nerve organs. Hence we come to associate light with visual sensations and to think of it as something like our sight feelings; to imagine sound as something like our auditory sensations; and so forth. As a matter of fact both light and sound are merely movements of ether or air; it is our own stimulated nerve centres which produce visual and auditory sensations; the ethereal or aerial vibrations merely act as the stimuli which give rise to nervous impulses in the nervous apparatus.

and moved by muscles. Opening along the edge of each eyelid are from twenty to thirty minute glands, called the *Meibomian follicles*. Their secretion is sometimes abnormally abundant, and then appears as a yellowish matter along the edges of the eyelids, which often dries in the night and causes the lids to be glued together in the morning. The *eyelashes* are curved hairs, arranged in one or two rows along each lid. They help to keep dust from falling into the eye, and, when the lids are nearly closed, protect it from a dazzling light.

The Lachrymal Apparatus consists of a tear gland in each orbit, of ducts which carry its secretion to the upper eyelid, and of canals by which this, unless excessive, is carried off from the front of the eye without running down over the face. The *lachrymal* or *tear gland*, about the size of an almond, lies in the upper and outer corner of the orbit. It is a compound racemose gland, from which twelve or fourteen ducts run and open on the inner surface of the upper eyelid at its outer corner. The secretion spreads evenly over the exposed part of the eye by the movements of winking, and keeps it moist. It is drained off by two *lachrymal canals*, one of which opens by a small pore on an elevation, or papilla, near the inner end of the margin of each eyelid. The aperture of the lower canal can be readily seen by examining its papilla in front of a looking glass. The canals run inward and open into the *lachrymal sac*, which lies just outside the nose, in a hollow where the lachrymal and superior maxillary bones (*L* and *Mx*, Fig. 16) meet. From this sac the *nasal duct* proceeds and opens into the nose

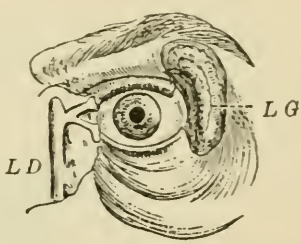

Fig. 126. Front view of left eye, with eyelid partly removed to show lachrymal gland, *L.G*, and lachrymal duct, *L.D*.

chamber below the interior turbinate bone (*q*, Fig. 46, p. 110).

Tears are constantly being secreted, but ordinarily in such quantity as to be drained off into the nose, from which they flow into the pharynx and are swallowed. When the lachrymal duct is stopped up, however, their continual presence makes itself unpleasantly felt, and may need the aid of a surgeon to clear the passage. In *weeping* the secretion is increased, and then not only more of it enters the nose, but some flows down the cheeks. The frequent swallowing movements of a crying child are due to the collection of tears in the pharynx.

Movements of the Eyeball.—Six muscles connect the eyeball with the wall of the cavity containing the eye. Four of

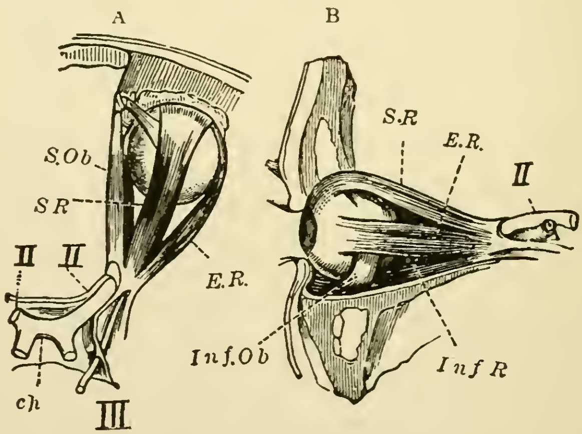

FIG. 127.—*A*, the muscles of the right eyeball viewed from above; *B*, the muscles of the left eyeball viewed from the outer side; *S.R*, superior retcus; *Inf R*, inferior rectus; *E.R*, external rectus; *S.Ob*, superior oblique; *Inf.Ob*, inferior oblique; *II*, the optic nerves; *ch*, their crossing or chiasma; *III*, the third cranial nerve.

these are attached around the entrance of the optic nerve at the back of the socket and extend forward, to be inserted into the eyeball near the edge of the transparent front part (*cornea*). These are called the *recti*, or *straight*, muscles (Fig. 88, *b*), and are further named according to their position, *external*,

internal, *superior*, and *inferior*. Each muscle when contracting rotates the eye toward itself. Two muscles, the *oblique*, are attached to the sides of the orbit and inserted into the eyeball behind the recti.

The motions of the eye produced by these muscles are chiefly from right to left and up and down. A combination of these two motions permits the eye to be turned in any direction. The eyes are so controlled through the nerves stimulating the muscles, that the axial lines of the globes of the eyes converge to pass through whatever object is looked at; hence the axes of the eyes are parallel to each other only when one looks at a distant object.

The Globe of the Eye is on the whole spheroidal, but consists of segments of two spheres (Fig. 128). A portion of a sphere of small radius forms its anterior transparent part, and is set upon the front of its posterior segment, which is part of a larger sphere. In general terms it may be described as consisting of three *coats* and three *refracting media*.

The outer coat (1 and 3, Fig. 128) consists of the *sclerotic* and the *cornea*. The cornea is transparent and is situated in front; the sclerotic is opaque and white and covers the back, sides and a part of the front of the globe, where it is seen between the eyelids as the *white* of the eye. Both are composed of dense connective tissue and are tough and strong.

The second coat consists of the *choroid* (9, 10) and the *iris* (14). The choroid consists mainly of blood vessels supported by loose connective tissue, which in its inner layers contains many dark brown or black pigment granules.* Towards the front of the eyeball, where it begins to diminish in diameter, the choroid separates from the sclerotic and turns

* In pink-eyed rabbits and occasionally in human beings this pigment is absent.

in to form the iris, the colored part of the eye which is seen through the cornea. In the centre of the iris is a circular dark aperture, the *pupil*, through which light reaches the interior of the eyeball.

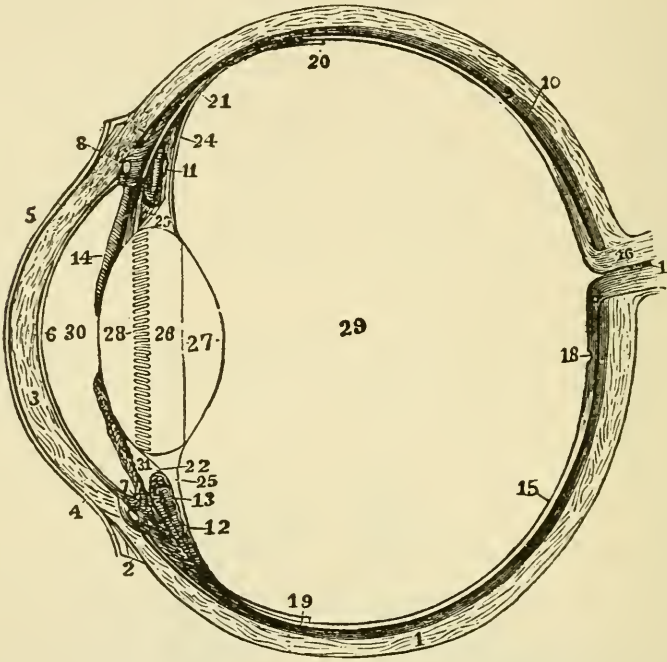

FIG. 128.—The left eyeball in horizontal section from before back. 1, sclerotic; 2, junction of sclerotic and cornea; 3, cornea; 4, 5, conjunctiva; 6, posterior elastic layer of cornea; 7, ciliary muscle; 10, choroid; 11, 13, ciliary processes; 14, iris; 15, retina; 16, optic nerve; 17, artery entering retina in optic nerve; 18, fovea centralis; 19, region where sensory part of retina ends; 22, suspensory ligament; 23 is placed in the canal of Petit, and the line from 25 points to it; 24, the anterior part of the hyaloid membrane; 26, 27, 28, are placed on the lens; 28 points to the line of attachment around it of the suspensory ligament; 29, vitreous humor; 30, anterior chamber of aqueous humor; 31, posterior chamber of aqueous humor.

The third or innermost coat, *the retina* (15), is the essential part of the eye, since in it the light produces those changes that give rise to nervous impulses in the optic nerve. It lines the posterior half of the eyeball.

The Microscopic Structure of the Retina is very complex; although but $\frac{1}{80}$ inch in thickness it presents ten distinct layers.

Beginning (Fig. 129) with its front or inner side we find the *internal limiting membrane* (1), a thin structureless layer;

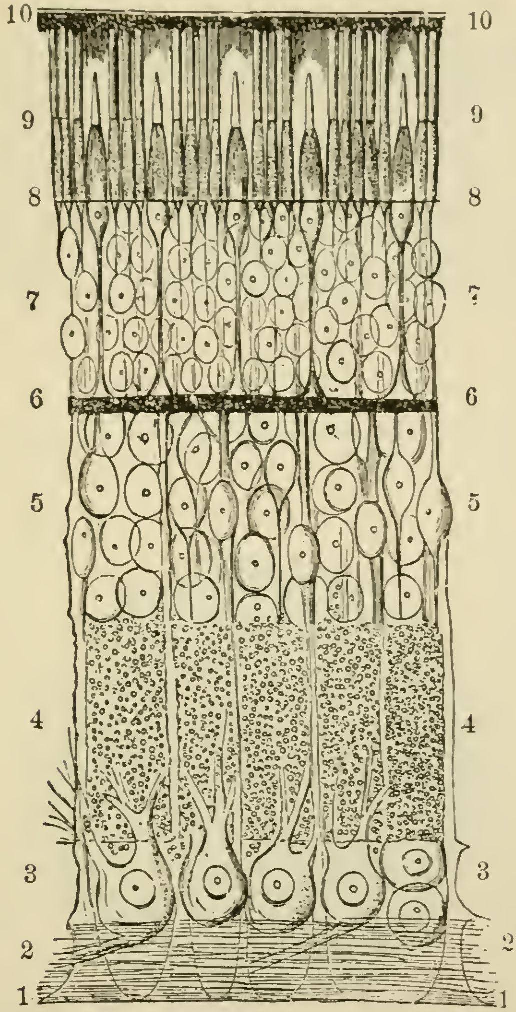

FIG. 129.—A section through the retina from its anterior or inner surface (1) in contact with the hyaloid membrane, to its outer (10) in contact with the choroid. 1, internal limiting membrane; 2, nerve-fibre layer; 3, nerve cell layer; 4, inner molecular layer; 5, inner granular layer; 6, outer molecular layer; 7, outer granular layer; 8, external limiting membrane; 9, rod and cone layer; 10, pigment cell layer.

the *nerve fibre layer* (2), formed by radiating fibres of the optic nerve; the *nerve cell layer* (3); the *inner molecular layer* (4), consisting partly of very fine nerve fibrils, and largely of

connective tissue; the *inner granular layer* (5), composed of nucleated cells: the *outer molecular layer* (6), thinner than the inner; the *outer granular layer* (7), composed of thick and thin fibres on each of which is a conspicuous nucleus with a nucleolus: the thin *external limiting membrane* (8), perforated by apertures through which the *rods and cones* (9) of the ninth layer join the fibres of the seventh: and outside of all, next the choroid, the *pigmentary layer* (10). The nerve fibres are believed to be continuous with the rods and cones. Light entering the eye passes through the transparent retina until it reaches and excites the rods and cones which stimulate the nerves.

The Blind Spot.—Where the optic nerve enters the retina it forms a small elevation (Fig. 130), from which nerve fibres

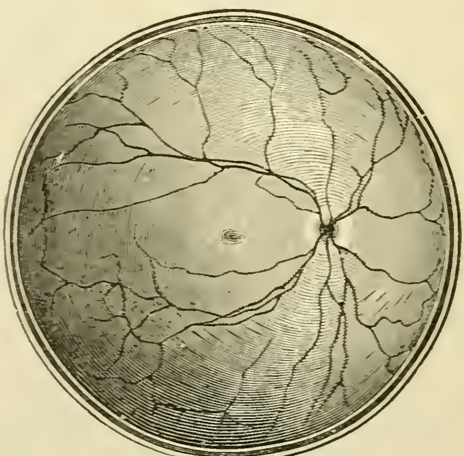

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FIG. 130.—The right retina as it would be seen if the front part of the eyeball with the lens and vitreous humor were removed. The white disk to the right marks the entry of the optic nerve (blind spot): the lines radiating from this are the retinal arteries and veins. The small central dark patch is the *yellow spot*, the region of most acute vision.

radiate. This elevation possesses neither rods nor cones and is blind, as may be readily demonstrated. Close the left eye

and look steadily with the right at the cross (Fig. 131), holding the page vertically in front of the face, and moving

FIG. 131.

it alternately from and toward you. When the book is about ten inches from the eye the white disk entirely diappears from view because its image then falls on the part of the retina where the optic nerve enters.

Light consists of vibrations in an ether which pervades space. An object which sets up no waves in the ether does not excite the visual nervous apparatus, and appears black; an object which sets up ethereal vibrations capable of exciting the rods and cones of the retina appears white or colored. The ethereal vibrations enter the eye through the cornea, pass on through the pupil and lens to stimulate the retina.

The Iris.—In the front portion of the eye behind the transparent cornea, and floating in the aqueous humor, lies a colored curtain (the *iris*) which forms a circle, with a hole (the *pupil*) in its centre. The iris has muscular fibres which enable it to make the pupil larger or smaller according as the light is faint or bright. All the light which goes to the retina must pass through the pupil, and the brightness of the images on the retina is dependent upon the number of rays which find their way through; hence a large opening gives brighter images than a small one. The iris by its adjustment of the

size of the pupil thus reflexly controls the amount of light and keeps the retina from injury by excess. It has another function: when we look at near objects the pupil becomes smaller than when we look at distant objects.* The iris thus acts as the diaphragm of a camera, since it is possible to form a sharp image of a near object only with a small bundle of rays.

When there is little light, as at twilight, the pupils are large and the eye cannot make distinct images, even of distant objects; hence everything seems blurred.

The Refracting Surfaces of the Eye are three in number: (1) the anterior surface of the cornea, (2) the anterior surface of the crystalline lens, and (3) the posterior surface of the crystalline lens (Fig 128). These surfaces act together like a convex lens, to bend the rays of light which pass through them (Fig. 132), so that all those which start from

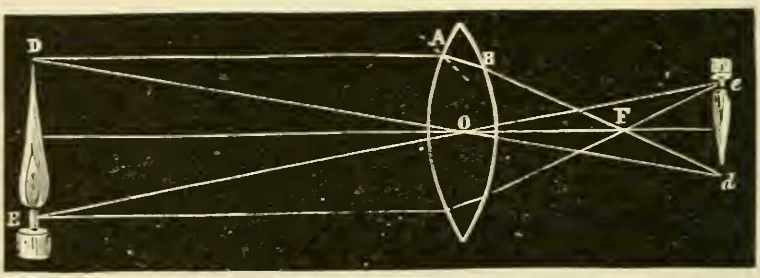

Fig. 132.—Illustrating the formation behind a convex lens of a diminished and inverted image of an object placed in front of it.

one point of an external object meet again in a *focus* on one point of the retina. In this way small and inverted images of the objects at which we look are formed on the retina, and stimulate its rods and cones.

* This change of pupil can be readily seen in another's eye by pressing the hand over it for a moment or two and then removing the hand.

Accommodation.—In the healthy eyeball the crystalline lens is controlled by muscles which change its convexity, making it greater when we look at near, and less when we look at distant, objects. Standing at a window behind a lace curtain we can *look at* the curtain and see its threads plainly, but while so doing we see houses on the other side of the street indistinctly, because the convexity of the lens is such

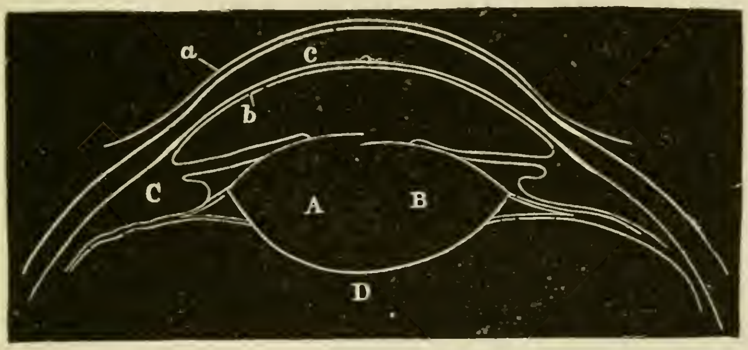

FIG. 133.—Section of front part of eyeball showing the change in the form of the lens when near and distant objects are looked at. *a*, *c*, *b*, cornea; *A*, lens when near object is looked at; *B*, lens when distant object is looked at.

as to focus light on the retina from the near object, and not from the distant. We can, however, "focus" on the houses over the way and see them plainly; but then we no longer see the curtain distinctly, because the lens has changed its form to focus light from the far object on the retina. The eye relaxes to focus on distant objects, and a muscular effort is necessary to increase the convexity of the lens, i.e. *accommodate*, for near objects.

Short Sight and Long Sight.—In the normal eye the range of accommodation is very great, making it possible to focus on objects infinitely distant or only six or eight inches from the eye. In the natural healthy eye parallel rays of light meet on the retina when the muscles controlling the crystalline lens are relaxed and the lens is at its flattest

(*A*, Fig. 134). Such eyes are *emmetropic* or *normal.* In some eyes the eyeball is elongated and when not accommodated parallel rays meet in front of the retina *(B)*. Persons with such eyes cannot see distant objects distinctly without the aid of diverging (concave) spectacles; they are *myopic* or *short-sighted.* In others, the eyeball is flattened, and when not accommodated parallel rays are brought to a focus behind the retina *(C)*. To see even distant objects, such persons must therefore use muscular effort to increase the converging power of the lens; and when objects are near they cannot bring the rays proceeding from them to a focus soon enough. To get distinct retinal images of near objects, they therefore need converging (convex) spectacles. Such eyes are called *hypermetropic* or *far-sighted.*

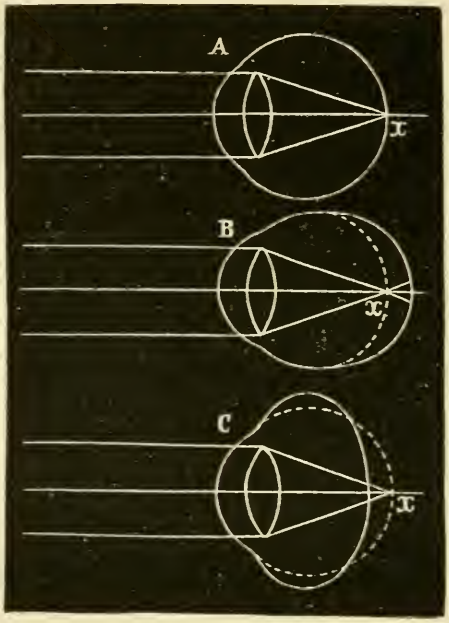

FIG. 134.—Diagram illustrating the path of parallel rays after entering an emmetropic (*A*), a myopic (*B*), and a hypermetropic (*C*) eye.

Astigmatism.—The refracting surfaces of the eye acting together are equivalent in refracting power to a single, spherical surface of fairly short curvature. Frequently, however, the result is not the same as would be given by a perfect spherical surface, owing to inequalities in the curvature of the eye. In one direction the curvature may be greater than that at right angles to it. This tendency to a cylindrical form is called *astigmatism.* It interferes with the formation

of perfect images and sometimes leads to serious eye strain in the effort to better the vision. Astigmatism may be detected by looking at black lines radiating from a point or at

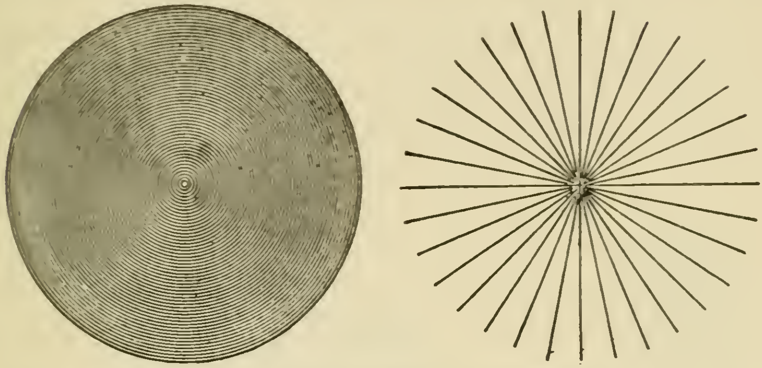

FIG. 135.—Lines for the detection of astigmatism.

fine black concentric circles. Portions of the lines or circles appear gray and others black; the gray portions are out of focus. This defect is corrected by proper cylindrical glasses which equalize the curvatures of the eye.

Hygiene of the Eyes.—Since the healthy eye is so constructed that when it is not accommodated it forms images of distant objects on the retina, muscular effort is required to see near objects, and fatigue results if the effort is long continued.

In a hypermetropic eye still more effort is needed to see near objects, and this results in greater muscular fatigue. Hypermetropic persons can often read well for a while, but then complain that they can no longer see distinctly. This kind of weak sight should always lead to examination of the eyes by an oculist; otherwise severe headaches may result and the eyes be injured.

Children sometimes have hypermetropic eyes, and should be at once provided with suitable glasses. In old age another kind of far-sightedness (*presbyopia*) is common, due to stiff-

ness of the crystalline lens, which cannot become convex enough during accommodation to focus the images of near objects on the retina.

Short-sighted eyes appear to be more common now than formerly, especially in those who use the eyes constantly at short range. Myopia is rare among those who live mainly out of doors. It is not so apt to lead to permanent injury

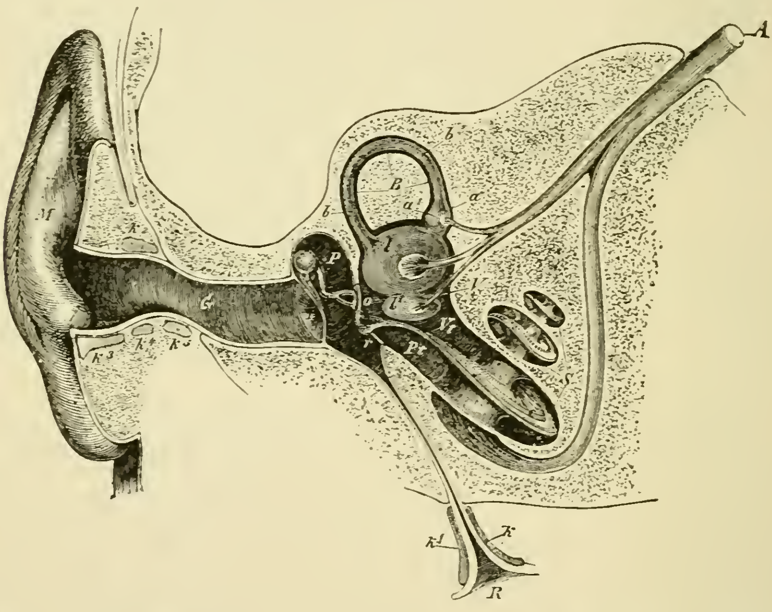

Fig. 136.—Semi-diagrammatic section through the right ear. *M*, concha; *G*, external auditory meatus; *T*, tympanic or drum membrane; *P*, middle ear; *o*, oval foramen; *r*, round foramen. Extending from *T* to *o* is seen the chain of tympanic bones. *R*, Eustachian tube. *V*, *B*, *S*, bony labyrinth: *V*, vestibule; *B*, semicircular canal; *S*, cochlea. *b*, *l*, *l′*, membranous semicircular canal and vestibule. *A*, auditory nerve dividing into branches for vestibule, semicircular canal, and cochlea.

of the eye as hypermetropia, but the effort to see distinctly any but near objects is apt to produce headaches and other symptoms of nervous exhaustion. Eye strain frequently shows itself in headaches and general nervous symptoms which do not appear to be associated with the eyes. They are, however, relieved when the eyes are cor-

rected by glasses. The general health also reacts upon the eyes and tends to exaggerate the nervous effects of eye strain.

Hearing.—The ear (Fig. 136) consists of three portions, known respectively as the *external ear*, the *middle ear*, and the *internal ear* or *labyrinth*. The latter is the essential hearing organ since it contains the ends of the auditory nerve fibres.

The External Ear consists of the expansion (*M*), seen on the exterior of the head, called the *concha*, and a passage leading in from it, the *external auditory meatus* (*G*). This passage is closed at its inner end by the *tympanic membrane* or *drum* (*T*). It is lined by a prolongation of the skin, through which numerous small glands, secreting the *wax* of the ear, open.

The Middle Ear, or drum chamber of the ear (Fig. 137 and *P*, Fig. 136), is an irregular cavity in the temporal bone, closed externally by the drum membrane. From its inner side the *Eustachian tube* (*R*, Fig. 136) proceeds and opens into the pharynx. This tube allows air from the throat to enter the cavity, and serves to keep equal the atmospheric pressure on ach side of the drum membrane.* Three small bones (Fig. 137) stretch across

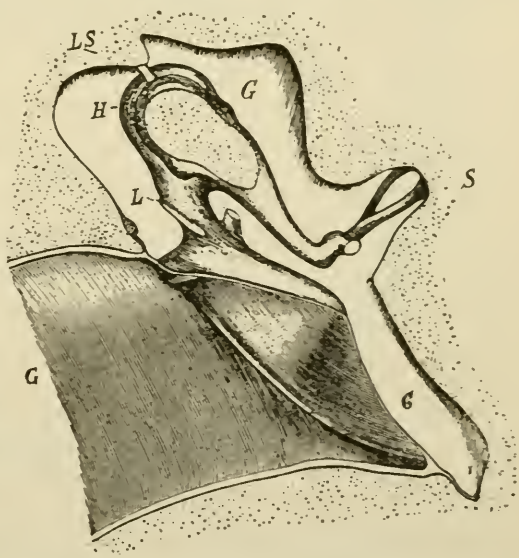

FIG. 137.—The middle ear and its bones, considerably magnified. *G*, the inner end of the external auditory meatus, closed internally by the conical tympanic membrane; *L*, the malleus, or hammer-bone; *H*, the incus, or anvil-bone; *S*, the stapes, or stirrup-bone.

* Frequently the inflammation of sore throat extends into the Eusta-

the cavity from the drum membrane to the labyrinth; they transmit the vibrations of the membrane, produced by sound waves in the external air, to the liquid of the labyrinth. The outmost bone is the *hammer* or *malleus;* the inmost, the *stirrup* or *stapes;* and the middle bone, the *anvil* or *incus.*

The Internal Ear, or Labyrinth, consists primarily of chambers and tubes hollowed out in the temporal bone. The middle chamber, called the *vestibule* (*V*, Fig. 135), has an opening, the *oval foramen* (*o*), in its outer side, into which the inner end of the stapes fits. Behind, the vestibule opens into three *semicircular canals* (one of which is shown at *B*, Fig. 135), and in front into a spirally coiled tube (*S*), the *cochlea.* In these bony chambers and tubes lie membranous chambers and tubes, in which the fibres of the auditory nerve (*A*, Fig. 135) end. All the labyrinth chamber outside these membranous parts is occupied by a watery liquid, known as *perilymph.* The membranous chambers are filled with a similar liquid, the *endolymph.*

The cochlea consists essentially of a tube coiled upon itself something like a snail shell. Partitions running through the length of the tube divide it into three cavities (Fig. 138), the middle and triangular-shaped cavity, which contains the auditory nerve terminals, and two side cavities. Each cavity is filled with endolymph. The membrane which divides the tube into nearly equal parts is called the *basilar membrane.* This supports the structure known as the *organ of Corti* in which the nerve terminals end (Fig. 138). The rods and cells which form the organ of Corti are continued with the basilar membrane throughout the length of the cochlea. The

chian tube and closes it. The air in the cavity of the middle ear is then absorbed and permits the external air to press the drum in, producing more or less deafness.

organ of Corti and the basilar membrane form a series of vibrating cords with corresponding nerve apparatus for receiving vibrations transmitted from the bones of the ear

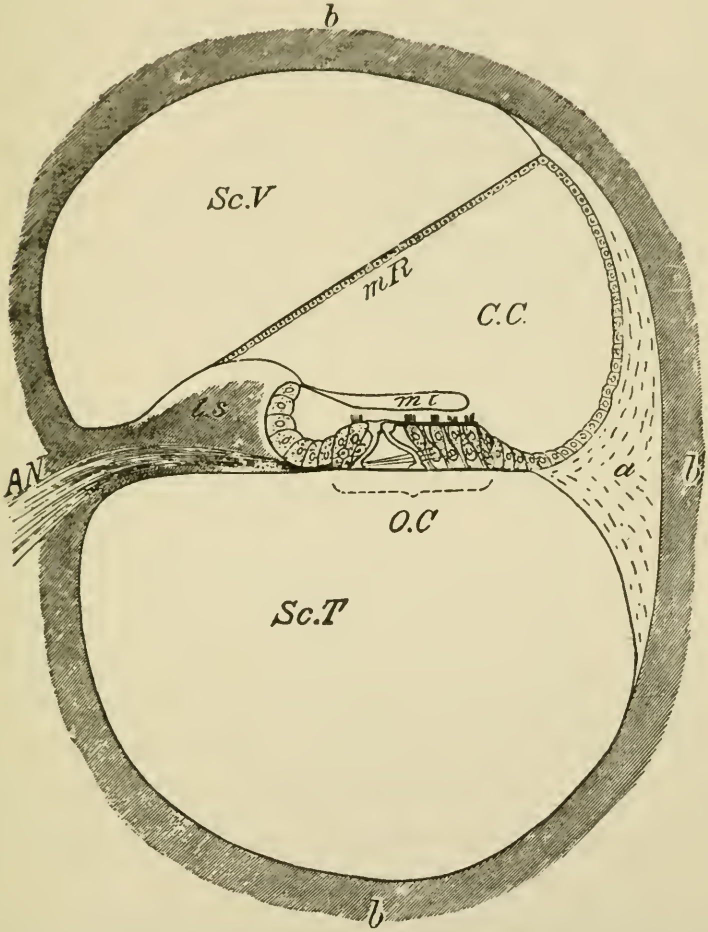

FIG. 138.—Diagram of a section of a coil of the cochlea. *C C*, canal of the cochlea; *mR*, its upper wall; *Sc V*, the part of the bony cavity above the canal of the cochlea; *Sc. T*, the part below it; *O.C*, the organ of Corti on the basilar membrane; *A.N*, branch of auditory nerve in the central column of the spiral; *a*, connective tissue cushion to which the basilar membrane is attached; *b*, the bony walls; *m.t*, a membrane lying over the organ of Corti; *l.s*, the spiral ledge projecting from the axis.

through the endolymph of the ear and for transforming them into nervous impulses. The vibrating cords of the basilar membrane are so arranged that they can respond to vibrations

varying in rapidity from 30 to about 20,000 per second. Each portion of the membrane has its own rate of vibration and is set in motion by vibrations of the same rate transmitted to it from the external air. Any vibrations in the endolymph will pick out the portions of the basilar membrane with corresponding vibrations and thus selectively create nervous impulses in the corresponding nerve terminals in the organ of Corti. These impulses transmitted to the auditory centre give rise to sensations which we recognize as sounds.

Sound.—The sensation which we know as sound is originated by oscillations produced in the air by vibrating bodies, such as a piano string or an organ pipe. A musical *tone* is caused by a regular succession of such oscillations. Loudness depends upon the extent, *pitch* upon the rapidity of vibration; slow vibrations give rise to deep, rapid vibrations to shrill, tones. A 16-inch organ pipe and the lowest string of the piano give about 33 vibrations to the second, their octave 66, and so on, doubling for each octave. A pure tone is of one pitch throughout, but each vibrating body gives out a complex sound made up of the vibration as a whole (*fundamental tone*), together with vibrations of parts of itself (*overtones*). The quality which enables us to distinguish between a piano and a violin, an organ or the human voice, depends upon the richness and character of these overtones. It is called *color*, or *timbre*.

The Semicircular Canals are associated with the *sense of equilibrium*.

Nerves are distributed to the ends of the semicircular canals and terminate in cells with hairs (Fig. 139). These hairs project into the endolymph of the cavity. They are arranged so that when an individual is standing one canal of each ear is horizontal, the second is vertical

antero-posteriorly, and the third is in the vertical plane at right angles to the second. Motion in any direction gives rise to a movement of endolymph through the hairs of the cells, just as water in a bucket which is suddenly rotated moves along the inner surface of the bucket. This causes pressure upon the hairs and leads to the transmission of nervous impulses which in turn give rise to the sensation of movement and equilibrium. Persistent dizziness has frequently led to diagnoses of disease in this region.

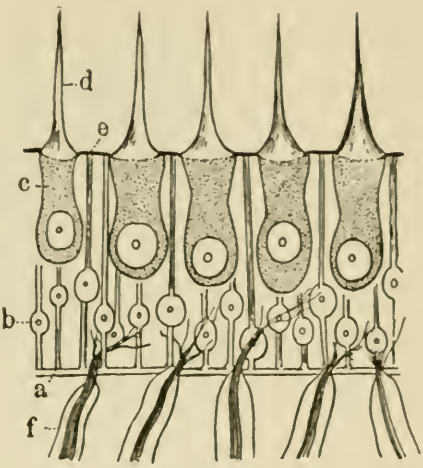

FIG. 139.—Diagram of epithelium in nervous region of ampulla of a semicircular canal.

Skin or Dermal Senses.—Many sensory nerves end in the skin through which we get several kinds of sensation. When a pencil point is pressed against the skin, we have a sense of touch and of pressure; when pressed very strongly, a sense of pain. When the point is pressed very lightly upon various points an occasional cold point is discovered. When a warm point is applied the sense of warmth is distinct and strong at certain points in the skin and weak at others. Each special sensation is probably due to a special nerve ending and nerve, capable of translating the stimuli (whether change of temperature, pressure, etc.) into nervous impulses which give rise in the brain to the corresponding sensation.*

By combinations of these sensations we get the charac-

* This is a marked illustration of the fact that nerves transmit special kinds of nervous impulses or have specific energy (*specific energy of nerves*).

teristics of the objects that we touch, of hardness, softness, smoothness, roughness, heat or cold, size, if the object is small enough to be received as a unit, and number, if several objects are applied to the skin at once, provided they are not too near together.

The Localization of Skin Sensations.—When the eyes are closed and a point of the skin is touched we can with some accuracy indicate the region stimulated; because, although tactile feelings are alike in general characters, they differ in something *(local sign)* besides intensity by which we can distinguish them as originated on certain parts of the skin. The fineness of the localizing power varies widely in different skin regions, and is measured by observing the least distance which must separate two objects (as the blunted points of a pair of compasses) in order that they may be felt as two. The following table illustrates some of the differences observed:

Tongue-tip	1.1 mm.	(.04 inch)
Palm side of last phalanx of finger	2.2 mm.	(.08 inch)
Red part of lips	4.4 mm.	(.16 inch)
Tip of nose	6.6 mm.	(.24 inch)
Back of second phalanx of finger	11.0 mm.	(.44 inch)
Heel	22.0 mm.	(.88 inch)
Back of hand	30.8 mm.	(1.23 inches)
Forearm	39.6 mm.	(1.58 inches)
Sternum	44.0 mm.	(1.76 inches)
Back of neck	52.8 mm.	(2.11 inches)
Middle of back	66.0 mm.	(2.64 inches)

It is supposed that the variations in discriminating power are dependent upon the richness of distribution of the tactile nerve ends, and that one or more untouched terminals must lie between those on which the compass points rest in order that *two* points may be distinguished.

The Muscular Sense.—Movements of the limbs are accompanied by a sensation of effort, which is proportional to the

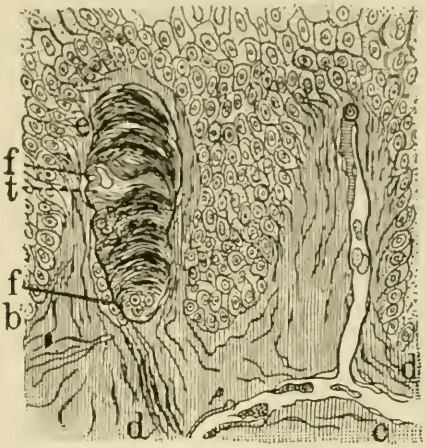

FIG. 140.—Section of skin showing two papillæ of the dermis and some of the deeper cells of the epidermis. *a*, papilla containing blood vessels; *b*, papilla containing a tactile corpuscle, *t*; *d*, medullated nerve fibres going to the corpuscle; at *f*, optical cross-sections of the fibres are seen as they wind round the outside of the corpuscle; the general transverse direction of the connective tissue bundles of the capsule of the corpuscle is shown.

energy expended and enables one to estimate the weight of the object moved and the direction of movement. These sensations have been called the *muscular sense.* They have been attributed to many causes and are now supposed to be due to a complex of nervous impulses received from joints, muscles, tendons, skin, etc. They give, in addition to sense of effort and of direction of movement, a sense of the position of the limbs. The muscular sense is exceedingly important as a subconscious guide to muscular control.

Pain may be described as a general sensation, since it has no special locality or peculiarity of manifestation. In general it is a danger signal to prevent injury, and guide to the way of health. While abnormal conditions in all tissues and organs may give rise to pain, the skin is far more sensitive than the deeper structures. Experiments suggest that there may be

special pain nerves, although their special terminal structure has not been identified.

Smell.—The endings of the olfactory nerves are spread in the mucous membrane of the upper parts of the nasal cavities. The olfactory cells are distributed between the cells of the mucous membrane (Fig. 141) and send fine filaments out to the surface. They are scattered over the upper and lower turbinate bones (*o*, *p*, Fig. 46) (which are expansions of the ethmoid on the outer wall of the nostril chamber), the opposite part of the partition between the nares and that part of the roof of the nose (*n*, Fig. 46) which separates it from the cranial cavity.

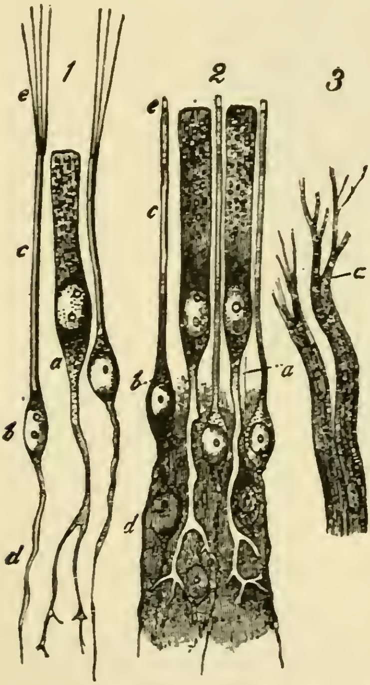

FIG 141.—Cells from the olfactory epithelium. 1, from the frog. 2, from man; *a*, columnar cell, with its branched deep process: *b*, so-called olfactory cell; *c*, its narrow outer process; *d*, its slender central process. 3, gray nerve fibres of the olfactory nerve, seen dividing into fine peripheral branches at *a*.

Odorous Substances, the stimuli of the olfactory apparatus, are ordinarily gaseous. They frequently act powerfully when present in very small quantity. A grain or two of musk kept in a room will give the air in it an odor for years, and yet at the end will hardly have diminished in weight. While some gases or vapors have this powerful influence upon the olfactory organ, others, as pure air, do not stimulate it at all.*

Taste.—The organ of taste is the mucous membrane on

* In ordinary breathing, the air passes through the lower part of the nose and therefore does not reach the olfactory surface. In "sniffing," the air is passed directly over this surface.

the upper side of the tongue, and possibly on the soft palate and fauces. The mucous membrane of the tongue presents innumerable elevations or papillæ (Fig. 53) of three kinds (p. 116). The filiform papillæ are organs of touch, for the tongue has the sense of touch as well as of taste. The circumvallate and fungiform papillæ contain the endings of branches of the glosso-pharyngeal and trigeminal nerves (pp. 241, 242), which, when excited by bodies in solution, stimulate the taste centres in the brain.

Many so-called tastes (flavors) are really smells; odoriferous particles of substances which are being eaten reach the nose through the posterior nares and arouse smell sensations which, since they accompany the presence of objects in the mouth, we take for tastes. Such is the case with most spices, since when the nasal chambers are closed by a cold in the head or by pinching the nose, the so-called "taste" of spices is not perceived, but only a certain pungency due to stimulation of nerves of common sensation in the tongue.

CHAPTER XXII.

VOICE AND SPEECH.

Voice consists of sounds produced by the vibrations of two elastic folds called the *vocal cords*. These cords lie in the *larynx*, which is situated between the pharynx and the windpipe, and is a portion of the air passage specially modified to form a voice organ.

The vocal cords project into the larynx so that only a narrow slit, the *glottis*, is left between them. When they are put in a certain position the air driven through the glottis sets them vibrating and they give rise to sounds. The stronger the blast the louder the voice.

The *pitch* of the voice is primarily dependent on the size of the larynx. The longer the vocal cords are, the lower is the pitch of the voice. Children, in whom the larynx is small, have shrill voices: and for the same reason a woman's voice is usually higher pitched than a man's. About sixteen or seventeen years of age a boy's larynx grows very fast, and his voice becomes about an octave deeper in tone.

While every one's voice has a certain natural pitch which leads us to call it soprano, tenor, bass, and so forth, this pitch can be modified within limits, so that we each can sing a number of notes. This variety is due to the action of muscles in the larynx which alter the tension of the vocal cords.

The more tightly they are stretched the higher pitched is the tone which they emit.

Resonance.—Although musical instruments depend primarily upon vibrating bodies, yet the volume and quality of their tones are largely determined by resonance chambers, as in the cornet and organ, or by sounding boards, as in the piano and violin. When a tuning fork is held in the fingers and tapped it gives a very low tone. When, however, it is touched to a hollow box open at one end and so constructed that the air column contained in it will vibrate in unison with the tuning fork, the volume and purity of the sound are enormously increased.

The pharynx, mouth and nose cavities act as a resonance chamber for the vibrations of the vocal cords, picking out and reinforcing the tones to which the air contained in them corresponds in rate of vibration. When the vocal cords vibrate they set the air in vibration. The sound is made louder and changed in character by this selective emphasis on fundamental tones and overtones.

Speech.—By movements of throat, soft palate, tongue, cheeks, and lips, the size and form of the resonance chamber are varied, and with them the tone of voice. By movements of tongue, lips, and palate, the air current, and therefore the sound, is interrupted from time to time, or the air is forced through a narrow passage in the mouth, giving rise to sounds in addition to those originated by the vocal cords. The primitive feeble monotonous tone due to the vibration of the vocal cords is thus reinforced and altered in throat and mouth, and *voice* is developed into articulate *speech*.

The Larnyx consists of a framework of nine cartilages, movably articulated together, and having muscles attached to them by whose contractions their relative positions are altered.

These cartilages form a tube, continuous with the windpipe and lined by mucous membrane. At one level the vocal

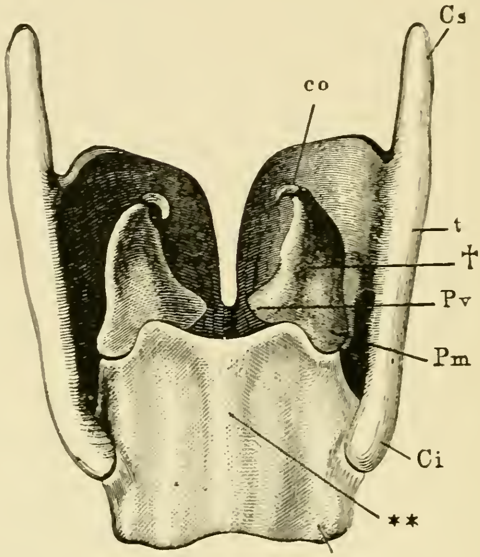

FIG. 142.—The more important cartilages of the larynx from behind. *t*, thyroid; *Cs*, its superior, and *Ci*, its inferior, horn of the right side; **, cricoid cartilage; †, arytenoid cartilage; *Pv*, the corner to which the posterior end of a vocal cord is attached; *Pm*, corner on which the muscles which approximate or separate the vocal cords are inserted; *co*, cartilage of Santorini.

cords, also covered with mucous membrane, project into the tube, leaving for the passage of air only the narrow slit of the glottis.

The largest cartilage of the larnyx (*t*, Fig. 142) is the *thyroid*. It is placed in front and consists of right and left halves which meet at an angle in front, but separate behind so as to enclose a V-shaped space. The front of the thyroid cartilage causes the prominence in the neck known as Adam's apple. The *epiglottis*, not represented in the figure, is attached to the top of the thyroid cartilage and overhangs the entry from pharynx to larynx. It may be seen, covered by mucous membrane, projecting at the root of the tongue, if

the mouth is held open before a mirror, and the tongue held down. It is represented as seen from behind at *a*, Fig. 143. The *cricoid cartilage* (**, Fig. 142) has the form of a signet-ring, with its broad part turned toward the back of the throat, and placed in the lower part of the opening between the halves of the thyroid. The two *arytenoid cartilages* (†, Fig. 142) are placed on the top of the wide posterior part of the cricoid; each is pyramidal in form. The remaining laryngeal cartilages are of less importance.

The Vocal Cords, which are rather projecting pads of elastic tissue than cords in the ordinary sense of the word, proceed, one from each arytenoid cartilage behind, to the angle where the halves of the thyroid meet in front. When open, as in quiet breathing, the glottis (*c*, Fig. 143) is narrow in front and wider behind, and since air driven through the opening does not then set the margins of the cords in vibration, no sound is produced.

The Muscles of the Larynx.—The laryngeal muscles are numerous. One set of muscles pulls the arytenoid cartilages towards one another and thus narrows the glottis behind; air forced through the narrowed slit causes vibration of the cords and produces voice. Another set stretches and tightens the vocal cords by pulling the arytenoid cartilages backward, and thereby raises the pitch of the voice. A third set pulls the front of the thyroid cartilage nearer the arytenoids and so slackens the cords and lowers the pitch of the voice. A fourth set separates the arytenoid cartilages, and with them the vocal cords, and thus widens the glottis and allows air to pass through it without producing voice.

The Range of the Human Voice from the lowest note (*f* of the unaccented octave) of an ordinary bass to the highest note (*g* on the thrice accented octave) of a fairly good so-

prano is about three octaves: the former note is produced by 88 vibrations per second the latter by 792. Celebrated

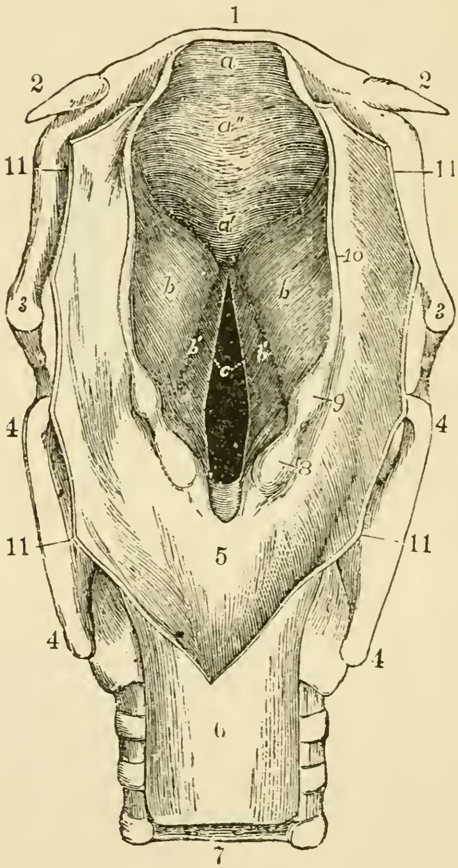

Fig. 143 —The larynx viewed from its pharyngeal opening. The back wall of the pharynx has been divided and its edges (11) turned aside. 1, body of hyoid; 2, its small, and 3, its great, horns; 4, upper and lower horns of thyroid cartilage; 5, mucous membrane of front of pharynx, covering the back of the cricoid cartilage; 6, upper end of gullet; 7, windpipe, lying in front of the gullet; 8, eminence caused by cartilage of Santorini; 9, eminence caused by cartilage of Wrisberg—both lie in, 10, the *aryteno-epiglottidean fold* of mucous membrane, surrounding the opening (*aditus laryngis*) from pharynx to larynx; *a*, projecting tip of epiglottis; *c*, the glottis—the lines leading from the letter point to the free vibrating edges of the vocal cords; *b'*, the ventricles of the larynxt—heir upper edges, marking them off from the eminences *b*, are the false vocal cords.

singers of course go beyond this limit in each direction: basses have been known to take *a* on the great octave (55 vibrations per second), and Mozart, at Parma, heard a soprano

sing a note of the extraordinarily high pitch *c* on the fifth accented octave (2114 vibrations per second).

Vowels are musical tones produced in the larynx and modified by resonance of the air in the pharynx and mouth. To get the broad *a* sounds, as *ah*, the mouth is widely opened and the lips drawn back. Such vowels as *oo* (*moor*) are produced by protruding the lips and lengthening the mouth cavity. The change in the form of the mouth may be noticed by pronouncing consecutively the vowel sounds *ah*, *eh*, *ee*, *oh*, *oo*. The English *i* (as in *spire*) is a diphthong, consisting of *ă* (p*a*d) followed by *ē* (f*ee*t), as may be readily found on attempting to sing a sustained note to the sound *i*.

Semivowels.—In uttering true vowel sounds the soft palate is raised so as to shut off the resonance of the nasal cavity. For some other sounds (the *semivowels* or *resonants*) the initial step is, as in the case of the true vowels, the production of a laryngeal tone ; but the soft palate is not raised, and the mouth exit is more or less closed by the lips or the tongue ; hence the blast issues partly through the nose, which by its resonance gives them a special character, as in the case of *m*, *n*, and *ng*.

Consonants are sounds produced not mainly by the vocal cords, but by modifications of the expiratory blast on its way through the mouth. The current may be interrupted and the sound changed by the lips (*labials*, as *p* and *b*); or, at or near the teeth, by the tip of the tongue (*dentals*, as *t* and *d*); or, in the throat, by the root of the tongue and the soft palate (*gutturals*, as *k* and *g*).

Consonants may also be classified by the kind of movement which gives rise to them. In *explosives* an interruption to the air current is suddenly interposed or removed (*p*, *b*, *t*, *d*, *k*, *g*). Other consonants are *continuous* (*f*, *s*, *r*) and may

be divided into (1) *aspirates*, when the air is made to rush through a narrow aperture, as, for example, between the lips (*f*), the teeth (*s*), the tongue and the palate (*sh*), or the tongue and the teeth (*th*); (2) *resonants* or semivowels; (3) *vibratories*, the different forms of *r*, due to vibrations of parts bounding a constriction put in the way of the air current on its passage.

CHAPTER XXIII.

GROWTH AND NUTRITION.

Development.—The human body, like the bodies of all animals, begins life as a single cell. This single cell divides to form two, these in turn form four, and so the process of division (*segmentation*) continues until there is a mulberry-like mass of cells which do not appear to differ one from another and which occupy about the same space as the original cell (Fig. 144). From this time on the continued

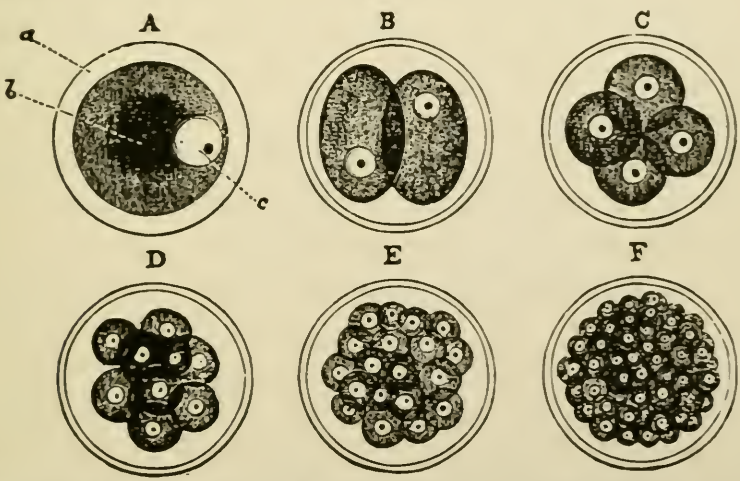

FIG. 144.—*A*, an ovum; *B* to *E*, successive stages in its segmentation until the *morula*, *F*, is produced; *a*, cell sac; *b*, cell contents; *c*, nucleus.

increase in number is accompanied by an increase in bulk. The cells no longer follow the same course of growth, but groups of cells develop peculiarities of their own, according

to a process known as *differentiation.* Ultimately three layers are formed. Each of these layers continues differentiating, with the result that from one layer the skin and the central nervous system are developed; from another the muscular and bony system; and from the third the alimentary tract.

The tissues resulting from this differentiation may be roughly classified in the following manner:

(1) Undifferentiated tissues. These are composed of cells with no special development, retaining much of the form and properties of rudimentary cells. Lymph corpuscles and some of the white blood corpuscles belong to this class.

(2) Supporting tissues, including cartilage, bone, and connective tissue.

(3) Nutritive tissues, including those cells which have to do with the reception and preparation of food, the secretion of digestive fluids, and the excretion of waste matters: as, for example, the cells of the stomach, intestines, lungs, kidneys, and skin, and the glands of the alimentary tract.

(4) Storage tissues, represented by the liver cells and such connective tissue cells as become loaded with fat.

(5) Irritable tissues, as the sense organs.

(6) Co-ordinating and automatic tissues, as the nerve cells.

(7) Motor tissues, represented by ciliated and muscle cells.

(8) Conductive tissues, as nerve fibres.

(9) Protective tissues, including the epithelial lining of the cavities of the body, the epidermis, hairs, nails, and the enamel of the teeth.

(10) Reproductive tissues, by which the ovum with its power of developing into a new individual is produced.

The cells making up the various tissues of the body have characteristic forms and powers. Cells with like powers, together with supporting cells, are grouped into masses called organs. These organs are placed in such positions as will interfere least with the activity of the body as a whole, and will best subserve, by their special activities, its welfare. The functions of any organ are the sum of the functions of the cells composing it. These cells may all have the same work to do, as in muscle, or may have different work, as in the glands of the stomach, some cells of which secrete pepsin, others hydrochloric acid, while both secrete water.

Cell Nutrition.—Each cell has work to do for the body as a whole; it has also to look after its own well-being in order to be able to do its work. This means that each cell of the bodies of the higher animals must take food materials in the form of serum albumin or globulin, sugar, oxygen, etc., must combine them into a compound which is capable of ready oxidation for the liberation of energy, must then be prepared to liberate this energy under the stimulation of nerve impulses, must direct the energy into useful channels, and get rid of the waste products of oxidation. It must appropriate substance and build it up into its own protoplasm for growth or repair. That these changes in cells may be considerable is shown by Fig. 145.

All the activities of the cell are stimulated and controlled by impulses received through connected nerves. The nervous impulses which have to do with the nutrition, growth, and general condition of the cell itself are supposed to be distinct from the impulses which stimulate the cell to work for the body as a whole, and have even been supposed to be transmitted to the cell through special nerves (*trophic nerves*). The cell may thus be considered an individual member

of a community with certain duties and privileges of its own.

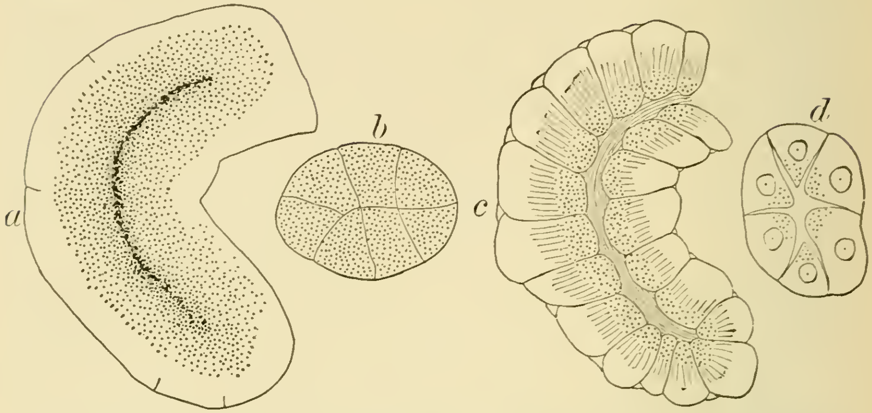

FIG. 145.—Serous glands. *a*, rabbit's pancreas "loaded" (resting); *c*, "discharged" (active) (observed in the living animal) (Kühne and Lea). *b*, loaded; *d*, discharged, alveolus of parotid (fresh preparations) (Langley).

General Nutrition.—We have seen that the cells making up the body have work to do both for themselves and for the other cells of the body, thus forming a vast army with one general plan of campaign. While we have definite knowledge of many of the general conditions under which the cells work, and of their contributions to the human economy, yet there is much which we do not know. When the body is deprived for a considerable time of certain salts and acids, it becomes weak and diseased (scurvy), but we do not know in what the efficacy of the acids and salts consists. We can only infer that they influence the cells and enable them to do their work better. Again, up to a certain point an increase of exercise for the cells of the body means an increase of power, and apparently their full power is not reached unless this opportunity for practice and exercise is given them. When thus exercised they become larger as well as more effective. Other tissues than those exercised also feel the stimulus. This is especially true of the exercise of the mus-

cles, which seems able, by making indirect demands upon the other cells of the body, to bring about the full development of all. Even the passive tissues, such as bone and tendon, are influenced through muscular exercise.

Animal Heat.—Cellular activity produces energy in forms useful to the body, including heat. We have seen that a certain amount of heat is necessary, since all the tissues of the body work best at a temperature of 39° C. (98° .5 F.). It is easily demonstrated that under normal conditions the temperature of the body remains constant at this optimal temperature throughout life.

Muscular activity furnishes far more heat than any other form of activity in the body. It has been found by experiment that of the potential energy set free in the oxidation of material in the muscles two thirds appear as heat, whereas only one third does work as muscular energy. Heat is, therefore, developed in proportion to the amount of muscular work done, and in hard work a much larger amount of heat is produced than is necessary to maintain the body temperature. This excess of heat becomes a waste product which must be got rid of in order to prevent a rise in body temperature (fever).

Heat Control.—A definite mechanism for the control of the heat loss exists in the body to insure the maintenance of the best temperature. The heat is carried by the blood from the heat-producing centres, muscles, glands, etc., to all parts of the body, including exposed inactive tissues, such as the skin, lungs, ears, nose, fingers and toes. The presence of an excess of heat reflexly stimulates the blood vessels of the skin to dilate and the perspiratory glands to secrete. The result is that a large mass of blood is thrown into contact with the cooler surface of the body, which is being still further cooled

by the evaporation of the moisture. The blood rapidly loses its heat and goes back to the interior parts of the body cooler, again to take up the heat, carry it to the surface and get rid of it. An increased amount of heat is also got rid of by the lungs during the more rapid breathing accompanying severe work.

During rest a reverse process takes place. The blood vessels of the skin reflexly contract, keeping the blood within the interior of the body, which is now protected from heat loss by a thick layer of skin and fat. This process of vaso-motor control has been likened to the taking off and putting on of an overcoat. Cold blooded animals are without this mechanism and have a variable temperature, dependent upon that of the medium in which they are. In summer a frog may have a temperature of 100° F., in winter of 33° or 34° F.

Fever.—In the condition known as fever, the temperature of the body is raised above the normal. This is thought to be due in most cases to the following factors: first, reduction in the amount of perspiration which ordinarily accompanies fever (dry skin), hence diminished heat loss through its evaporation; second, increased production of heat by unusual activity and consequent heat formation in the tissues; and third, disarrangement of the heat-controlling nerve mechanism.

Fever is not primarily a disease, but a symptom of several diseases, and depends upon varying factors rather than upon any particular set of conditions.

Internal Secretion of Glands.—We have seen that some glands secrete fluids which they carry through ducts to surfaces more or less remote from themselves. There are certain glands of the body, as the spleen, the thyroid gland, etc.,

which have no ducts and whose only connection with the rest of the body is by means of the blood passing in through the artery and out through the vein; hence their secretion must be given to the blood to be carried to the rest of the body *(internal secretion)*. This makes it very difficult to determine the real functions of these organs experimentally, since large amounts of blood pass through them in twenty-four hours, and substances, even if given off in considerable quantities in their secretions, are so greatly diluted as to escape detection.

The *spleen* is situated in the left side of the abdominal cavity under the eleventh rib. It is a large mass of cellular tissue supported by a framework of connective tissue, into which the blood escapes from the open ends of the blood vessels in its passage through it. In malaria and in certain blood diseases associated with a large increase of white blood corpuscles the spleen becomes greatly enlarged. Apart from its function of giving off white blood corpuscles, little is known of the spleen, as it can be removed without serious results.

The *thyroid gland*, which lies on either side and below the larynx; the *thymus gland*, which is found near the thyroid; the *suprarenal capsule*, the small gland lying above each kidney; and the *pituitary body*, a very small gland lying at the base of the brain, are other examples of ductless glands.

That these last named glands have important functions is shown by cases of disease and by experiments made on animals in which the glands were removed. When the thyroid gland is removed from the body, the tissues become more or less gelatinous, the animal weakens and soon dies. When the secreting cells of the thyroid gland are destroyed in man by disease, a similar condition of the tissues follows. If the thyroid glands from pig or sheep are then eaten, the tissues again recover their character and strength is regained, show-

ing a definite relation between the abnormal condition of the tissues and the secretion of the glands.

Removal of the suprarenal capsules leads quickly to death. Disease of the capsules is associated with muscular weakness and pigmentation or bronzing of the skin. Experiments have shown that the secretion of these capsules is undoubtedly closely associated with the vaso-motor control of blood vessels.

Removal of the pituitary body leads also to rapid death, with symptoms somewhat resembling the removal of the thyroid gland. Disease of the pituitary body in man is associated with a curious condition of enlargement of the bones of the body (*giantism*).

Experiments have shown that the kidney, beside its function of the external secretion (excretion) of urine from the blood, acts apparently as a ductless gland. When three quarters of the secreting substances of the two kidneys have been removed (one half of one kidney and the whole of the other), the secretion of urine is carried on adequately, but the animal, in spite of a voracious appetite, rapidly wastes away and dies, showing that the kidney must contribute to the blood substances essential to health.

Removal of the pancreas or disease affecting certain of its cells leads to a secretion of sugar from the kidney (*diabetes*) and to a rapid wasting of the body and final death.

Experiments have shown that an animal cannot survive the removal of the liver, although the entire secretion of the bile may be poured out on the surface of the body through a fistula and lost without serious harm. This shows that its internal secretion is also of extreme importance.

The essential result of interference with the internal secretions of the glands seems to be a profound disturbance of nutrition, which, though it assumes various aspects, is distinctly

related to the power of the cells in assimilating and utilizing food material and in performing their work.

Health.—We have seen that the cells of the body act as individuals in the work of the body, and that their efforts are controlled by the nervous system, in order that a balanced effort toward the one end of maintaining the body's effective power may be obtained. We may therefore define *health* as that condition in which the work of each cell of the body is perfectly done through the proper co-ordination and balance of all.

Disease thus becomes a condition in which the working power of cells in a part of the body is reduced or lost or the balance destroyed.* Tissue cells are hindered in their work or even destroyed by certain minute unicellular parasitic plants called *bacteria*. Some of these have the power of developing in the body, interfering with its balance, and directly destroying the cells of the tissues. They also develop poisonous substances through their own activity (ptomaines),† which, when carried away by the blood, may overwhelm the vital powers and finally produce death.

Immunity from Disease.—Certain diseases are communicated from individual to individual and are classed as contagious and probably bacterial, though this has not been demonstrated in the case of all. The most common are scarlet fever, diphtheria, smallpox, typhoid fever, yellow fever, cholera, plague, and tuberculosis (consumption). In some of these diseases, as measles, mumps, and scarlet fever, one

* Some diseases are not thoroughly understood and cannot be classified in this way. Most diseases, however, come within the two classes named.

† These disease-producing bacteria may be grown on certain substances as bouillon, gelatin, potato, etc. When thus cultivated they give rise to substances among the most poisonous known.

attack ordinarily protects against a second attack and the individual thus protected is said to be *immune* to them.

It has been recently shown by experiments that when the blood of an animal which has recently had the disease is injected into the blood of another animal, it will give the latter immunity, even when the disease germs are inoculated directly into its tissues. This has been applied in certain diseases, notably diphtheria, in the following manner:—The poisonous substance (*toxin*) developed in cultures of diphtheria bacilli, and carefully filtered to remove all living bacilli, is injected into a horse in successive doses, each one so small that it is not fatal. After weeks or months of continuous dosing, the horse is apparently perfectly well and vigorous. The serum of its blood when injected into the subcutaneous lymph spaces and thence absorbed into the blood of a man is capable of making all the tissues of the body unfriendly to the diphtheria bacilli, and of protecting the individual entirely from their ravages. More than this, it may even be capable, under favorable circumstances, of destroying bacilli which have already a foothold and have produced the symptoms of diphtheria. It is inferred that a new substance (*antitoxin*) has been formed in the blood. The production of the antitoxin is thus apparently a distinct reaction of the body to the stimulus of the toxin in such a way as to neutralize its bad effect, provided that the vitality of the tissues has not been already too far lowered by an overwhelming amount of toxin.

The immunity gained by a previous attack of the disease is in like manner probably due to the antitoxin developed in the body as a reaction to the toxin of the disease. Since vaccination protects against smallpox, it is probable that cowpox (vaccinia) is a modified form of smallpox.

The immunity of scarlet fever, smallpox and yellow fever

may last for years or even for life, whereas that of diphtheria is for a few weeks only; of tuberculosis none has been discovered. Whether this difference is due to the fact that the antitoxin is produced by the body only during the presence of the toxin (i.e. during the disease) and that the duration of the immunity depends upon the rapidity with which the antitoxin is eliminated from the body, or that the formation of the antitoxin by the tissues continues, after being once started by the toxin, for periods which vary in different diseases, has not been determined. It is probable that the power of the tissues to develop the protective substances is limited and is perfect only in a few diseases. It may be possible, however, eventually, by the use of animals for the development of antitoxins or for the modification of disease-producing bacilli, to stamp out contagious diseases by giving immunity, as has been done in the case of smallpox.

APPENDIX A.

EMERGENCIES.

SUFFOCATION.

Suffocation—Gas Poisoning.—In cases where a person is deprived of oxygen, the vital powers may become so much depressed that life appears extinct. This may be due to interference with the act of breathing; to the presence of gas, as carbon dioxide or illuminating gas, in such quantities as to displace the oxygen; to submersion in water; or to enclosure in a small space from which the oxygen is readily used up in the regular process of breathing and cannot be renewed. Ordinarily suffocation is complicated with poisoning by gases.*

Treatment:—Remove the patient into the fresh air. Dash cold water into the face, slap the chest and tickle the nose. Hold ammonia under the nostrils or take the tongue in a dry handkerchief and every four seconds draw it out with moderate force. If these measures fail to re-establish breathing, artificial respiration must be immediately undertaken.

Artificial Respiration is used in all cases of suffocation and drowning in which natural respiratory movements have

* Illuminating gas contains the very poisonous gas, carbon monoxide, which unites with the hæmoglobin of the blood to displace the oxygen in the red corpuscles.

ceased. If an individual has been under water, the lungs are naturally filled with water and should be at once emptied. Turn him on his face, clasp your hands under the lower chest and raise him from the ground: the pressure upon the lower chest will compress the lungs and tend to empty them of water. Repeat two or three times, taking care not to injure the face by rough handling. Do not, however, delay artificial respiration in the attempt to remove all of the water.

Wipe out the mouth and throat. Turn the patient over on his back with something under his back and shoulders so that the head will rest well back. Pass a pin through the tip of the tongue. Draw the tongue out from the mouth; pass a string around it back of the pin, cross it over the chin and tie it behind the head so that the tongue will be held forward and will not close the air passage into the larynx.* Loosen the clothing, and, if wet, cover it with dry.

Place yourself at the head of the patient, grasp his forearms near the elbow and carry them upward so that they lie parallel at each side of his head (Fig. 146). Let them rest there for a moment; notice that air enters through the nose and mouth. Then carry the arms back and press them upon the chest (Fig. 147); notice that air is expired. Repeat this regularly every three or four seconds.

After five or ten minutes of artificial respiration, it may be best, if in winter, to remove the patient to a warm place. During the time of removal continue, if possible, artificial respiration and especially rhythmic pressure in the region of the heart every one or two seconds, since this may tend to

* This is necessary only when no one else is present to hold the tongue. If two are present. friction upon the limbs should also be employed.

keep the blood in circulation and carry aerated blood from the lungs to the tissues.

FIG. 146.—Showing position for inspiration.

FIG. 147.—Showing position for expiration.

Hot water applied to the heart stimulates its action, and an electric battery, one pole of the induction coil applied to

the back of the neck and the other to the region of the diaphragm, may also be useful for this purpose.

Warm water may be injected into the rectum, 100° F., to aid in restoring the heat of the body. Hot cloths, hot water bottles, hot bricks, etc., should also be applied externally as soon as possible, but burns should be avoided.

Stimulants may be given by the mouth if the patient is able to swallow: if not and the heart is still beating, they will, if given in the rectum, be absorbed and carried by the blood to the respiratory and cardiac centres.

Artificial respiration should be continued for one or two hours if necessary, as there is always hope if the pulse or heart beat can be detected. After treatment, avoid shock by keeping the patient quiet in bed and use stimulants as freely as needed. Persons have been saved after being under water as long as twelve to fifteen minutes.

Choking.—Solid objects too large to be swallowed or accidentally caught in the larynx lead by their presence to reflex spasms of the epiglottis and closure of the respiratory tract. The result is a more or less complete but usually temporary suffocation. Distress and violent coughing are prominent symptoms.

Treatment:—Strike the patient strongly with the flat of the hand on the back. Lay him on a bed or chairs with the head and upper part of the chest hanging over. Let him take a full breath and then make sudden pressure on the back as he expires. In a child, raising by the feet may aid in dislodging the object. If ineffective, do not waste time, but pass the finger down the throat, taking the precaution to insert a folded handkerchief between the teeth to avoid being bitten. An ordinary finger is long enough to reach to the larynx, and the object may be felt and removed. An emetic

of mustard water is sometimes effective if the object has not passed too far. Avoid exhaustion of patient in the attempts at removal, since objects which can pass through the œsophagus by the larynx will do no harm if they are assisted in their passage by masses of food with large waste, as potato and turnip.

At times children are taken suddenly with croup, the symptoms of which resemble those of choking. Give the child warm water or, better, a teaspoonful of syrup of ipecac, and repeat until vomiting occurs. Apply hot water, ice, or mustard plasters to the throat. Send for the doctor.

UNCONSCIOUSNESS.

Symptoms and Treatment.—Unconsciousness may be caused by so many conditions that it is well to examine a person who is unconscious to determine the cause, if it is not known. The general treatment for unconsciousness may be begun while the examination is being made.

Send for a physician.

Place the patient on his back. Loosen the clothing about throat and chest. Give him plenty of fresh air, and if the breathing has ceased while the pulse is still felt, apply artificial respiration. Do not give stimulants if the face is flushed or if the pulse is strong, since they increase the heart's action and, in case of ruptured blood vessels in the brain, the bleeding and consequent injury of the brain tissue. If the temperature of the body is raised, apply wet cloths or ice. Note if there is fracture of bones, including ribs, collar bone, and skull. Run the fingers down the spinous processes of the vertebræ and note if they are uniformly distributed in a

straight line. Open the eyes and see if the pupils are dilated, contracted or equal in size. Note odor of breath.

Unconsciousness may be due to (*a*) narcosis by ether, chloroform, opium, morphine, chloral, aconite, etc., the treatment of which is given under Poisons, below; (*b*) fainting; (*c*) sunstroke; (*d*) convulsions; (*e*) alcohol poisoning; (*f*) concussion of brain; (*g*) epileptic attack; (*h*) apoplexy.

Fainting.—The pulse is found weak, the face pale.

Treatment :—Place patient upon his back, with the head and chest lower than the rest of the body. If there is vomiting, place him upon his side. Apply smelling salts, or give ammonia, strong coffee, brandy or whiskey. Insure plenty of fresh air by fanning, and avoid excitement.

Sunstroke.—When working on a hot sunny day, or on warm days when the air is full of moisture, persons are sometimes overcome with the heat, having headache, weakness, and difficulty of vision. The individual quickly becomes unconscious, and may even fall so as to be injured. The body is usually hot to the touch, the skin dry, the face flushed, the pulse full and rapid, but there may be coldness, pallor, and weak pulse. Twitchings of the body may also be noticed.

Treatment :—Reduce the heat of the body as rapidly as possible by throwing cold water over the patient and applying ice to the head. Strip the body and wrap it in a sheet kept wet by frequent applications of water. Continue until consciousness is regained or the temperature of the body is lowered. Do not send the patient to his home or to a hospital until after the treatment has been begun. If the patient does not exhibit symptoms of high temperature, but shows pallor of face and weak pulse, do not use cold applications, but give rest, quiet, food and stimulants in cautious amounts.

Convulsions.—Children may have these attacks as a result of disorders of the stomach, or of fever.

Treatment :—Keep the child from injuring himself. Put him into a warm bath or wrap him in a blanket dipped into hot water. Keep the head cool by applying cold water or ice. If the convulsions continue, give an emetic, as a teaspoonful of syrup of ipecac, if the child can swallow. Assist vomiting by thrusting the finger down the throat or by using a feather. Give injection of soap and warm water, as the seat of irritation may be in the lower bowel.

Alcoholic Poisoning—Drunkenness.—The pulse is full or, later, weak. The breathing is natural, the pupils of eyes of equal size, and when the eye is touched the eyelid will close immediately. The patient can usually be roused to speak. Alcoholic odor in the breath is always present, but is not an infallible symptom. The diagnosis of intoxication should not be made unless it is an absolutely clear case, since many persons have died from apoplexy or head injury when they were supposed to be drunk.

Treatment :—If the patient has not already vomited, turn him on his face and raise him with clasped hands under the abdomen. If not effective, give an emetic of mustard water. If there are symptoms of collapse, as cold skin and feeble pulse, apply heat and give stimulants, as ammonia, coffee, or strychnia.

Concussion of Brain.—Unconsciousness may be due to a blow on the head which produces temporary unconsciousness, or gives rise to compression of the brain by fracture of the skull or by bleeding due to laceration of brain tissue. The symptoms are more or less similar to those of apoplexy. Bleeding from the ear shows that there has been a fracture of the base of the skull.

Treatment :—Keep the patient in a cool quiet place, with the head slightly raised. Avoid strong light and all excitement. Loosen the clothing. If the body is cold, apply heat. Do not give stimulants unless the pulse is very weak.

Epileptic Attacks may come on suddenly or gradually with symptoms which the patient recognizes. Loss of consciousness may be accompanied by a peculiar cry, sudden pallor of the face, and more or less stiffening of the body. The tongue is sometimes bitten and the eyes have a peculiar upward rolling motion. An attack usually lasts for a minute or two only, but several attacks may follow each other rapidly.

Treatment :—Keep patient from injuring himself, but do not struggle with him. Allow him to lie flat, and put a piece of folded cloth between the teeth to prevent biting of the tongue. The muscular contractions if prolonged give rise to exhaustion and lameness, but these may be lessened by putting the patient into a bath of warm water. After the attack put him to bed and if necessary use stimulants in small quantities.

These attacks are seldom serious, and it is usually unnecessary to do anything except prevent bodily injury.

Apoplexy is due to bleeding from a ruptured blood vessel in the brain and consequent pressure of the blood upon the brain tissue. The nerve cells or nerve fibres when pressed upon cease to perform their functions and more or less unconsciousness and paralysis result. The face is flushed, the pupils of the eyes more or less dilated and perhaps unequal in size, the breathing slow, irregular, and noisy, the cheeks puffed out and drawn in with the air movement, and the pulse slow and full. There may be also convulsions and vomiting. An important symptom is one-sided paralysis. Notice whether the face is drawn to one side (away from the paralyzed side) or the head kept on one side.

Treatment :—Keep the patient absolutely quiet, lying down, the head moderately raised. Apply cold water or ice to the head. If the patient can swallow, give castor oil or a dose of salts. The bowels may be emptied by giving injection of soap and warm water. Do not give stimulants.

POISONS.

General Treatment:

1) Send for the nearest doctor

2) Empty the stomach by the use of

a) Emetics to produce vomiting:

Tickle throat with finger or feather.

Mustard water, tablespoonful to tumbler of tepid water.

Salt water, tablespoonful to tumbler of tepid water.

Zinc sulphate, 20 to 30 grains to half a tumbler of tepid water.

Copper sulphate, 10 grains to 2 ounces of warm water.

Ipecac, 30 grains of powder or 2 tablespoonfuls of the wine or the syrup of ipecac.

Caution: Emetics are valueless when taken after substances which produce anæsthesia of throat and stomach and after powerful corrosives (as opium, morphine, carbolic acid, aconite, cocaine, strong acids and alkalies), have had time to act.

b) Stomach tube. Use any rubber tube two feet or more in length by one half inch diameter. In introducing it, avoid the larynx and get the

patient to make swallowing movements. Measure on the tube the distance from the stomach to the mouth with the head thrown back, and insert only enough of the tube to reach the stomach, so as to avoid perforation in case of corrosion. Pour water through a funnel into the tube; then drop the end of the tube and press upon the abdomen to force out the contents of the stomach. This may be repeated and neutralizing substances introduced, alkalies for acids, acids for alkalies.

3) Give antidotes:

a) Chemical (which destroy the power of the poison). (See Special Poisons.)

b) Physiological (which neutralize the constitutional effects of the poison; for example, stimulants).

4) Give diluents (which dilute and hence weaken the power of corrosives, water, milk or any harmless fluid).

5) Give demulcents (which tend to coat over the poisons, or furnish a protective coating to the stomach, or by their coagulation entangle the poison; for example, milk, white of egg, boiled starch, mucilage, boiled slippery elm bark). These are particularly valuable in the case of corrosive and irritant poisons

Constitutional Treatment:

1) Stimulants (which increase the power of the heart and overcome weakness and depression):

Aromatic spirits of ammonia or water of ammonia, tablespoonful in half glass of water; frequent small doses.

Alcohol, one or two teaspoonfuls in two ounces of water, or twice as much whiskey or brandy.

Coffee, in strong solution.

Vapor of ether inhaled or one teaspoonful in cold water.

Tincture of nux vomica, five to ten drops in water; or strychnia $\frac{1}{20}$ to $\frac{1}{60}$ grain.

Stimulants are not absorbed from the stomach if there is much corrosive action, as in the case of strong acids and alkalies; they may then be given by the rectum.

2) External heat (of special value in depression).

Apply warm blankets, hot water bottles, hot bricks, etc.

Caution: In case of more or less complete loss of consciousness, apply nothing hot enough to burn.

3) Friction (to aid depressed circulation).

Rub toward the heart in order to aid the venous return. Keep the patient in a horizontal position, or, in case of profound depression, with the head and chest lower than the rest of the body. Sudden raising of the head should always be avoided.

COMMON POISONS AND THEIR ANTIDOTES.

Irritant Poisons (more or less corrosive):

Arsenic (paris green, Fowler's solution, arsenious acid, some vermin killers).

Precipitated oxide of iron, made by precipitating any solution of iron with ammonia, washing soda or any strong alkali in solution. Wash precipitate with water through a cloth. Give two or three tablespoon-

fuls. If the iron precipitate cannot be obtained immediately, give moistened plaster of wall which will mix with the poison and serve to protect the stomach. Wash out stomach.

Phosphorus (matches, Rough on Rats).

Emetics: magnesia, plaster from wall.

Empty stomach.

Caution: Do not give oily substances as milk, etc.

Corrosive sublimate (mercuric bichloride, bug poison).

White of egg; emetics. Wash out stomach.

Iodine (tincture).

Starch (boiled).

Lead (paints, hair dyes).

Sulphates (Epsom salts, Glauber's salts, alum), emetics, etc.

Cantharides (Spanish fly, irritant liniments).

Demulcents, diluents, camphor, and opium.

Caution: Avoid fat or oil.

Corrosives:

Acids [sulphuric acid = oil of vitriol (H_2SO_4); hydrochloric acid = muriatic acid (HCl); nitric acid (HNO_3)].

Water, dilute alkalies, lime water, soap solution, tooth powder, chalk or plaster of wall, followed by demulcents. Wash out stomach.

Carbolic acid.

Water, sulphates (Glauber's or Epsom salts) or alum. Roll patient to prevent corrosive action. Wash out stomach.

Oxalic acid.

Lime or chalk. Stimulants as needed. Wash out stomach.

Alkalies [caustic soda = sodium hydroxide ($NaOH$); caustic

potash = potassium hydroxide (KOH); ammonia = ammonium hydroxide (NH_4OH)].

Dilute acid, vinegar, hard cider, lemon or orange juice, followed by demulcents.

Narcotics:

Opium (laudanum, paregoric, morphine, black drops, McMunn's elixir, soothing syrups, cholera mixtures, Dover's powder).

Solution potassium permanganate, 10 to 15 grains in half a glass of water. Wash out stomach. Tannic acid, strong hot coffee, strychnia, $\frac{1}{20}$ to $\frac{1}{10}$ grain. Electric battery. Keep awake by non-exhausting means. Perform artificial respiration and maintain body temperature.

In opium poisoning a distinguishing symptom is pin-head contraction of the pupils of the eyes.

Chloral hydrate (chloral, knock-out drops).

Treatmen tsame as for opium.

Aconite.

Wash out stomach. Stimulants, as coffee, ammonia, alcohol.

Tobacco (snuff).

Tea or coffee, vinegar, and stimulants. Heat and friction.

Ether and chloroform.

Lower head and chest. Use artificial respiration. Stimulants, especially ammonia, nux vomica or strychnia.

Nux vomica (strychnia).

Vapor of ether or chloroform, to control the spasms. Bromide of potassium or sodium (20 to 30 grains),

chloral (20 grains) or morphine ($\frac{1}{4}$ to $\frac{1}{2}$ grain). Give in rectum if patient cannot swallow.

FIRST AID TO THE INJURED.

Dislocations.—When the end of a bone slips out of its joint, it is said to be dislocated. Owing to the arrangement of ligaments, dislocation is associated with more or less tearing of the capsular and reinforcing ligaments and bleeding from the ruptured vessels, followed by swelling and discoloration. The swelling of the joint is apt to be so great that it is wise to restore the bone as soon as possible. Compare it with its corresponding joint and attempt to restore it to its place; if successful apply a bandage, handkerchief or cloth in such a way as to keep the joint in place. It is well if the joint is accessible, as the ankle, elbow, etc., to apply a wad of cloth or other soft elastic material (compress) around the joint and then wind a bandage tightly over it to prevent swelling.

Fractures.—A fracture or break of a bone may usually be recognized by movement of the pieces or by crepitus when the broken ends are rubbed together. The pieces of bone should be brought as nearly as possible into their proper positions and held there by splints. Sticks, umbrellas, canes, pillows or folded sheets may be fastened with cords or bandages along the sides of the limb to stiffen it and hold it in position. To move such a patient it is necessary to put him on a board, shutter or other object so that he can lie at full length and be carried without jarring. An arm may be put into a sling passed around the neck. A broken leg may be bound to the sound one, taking care to draw the foot of the broken leg out to the full length of the sound one.

Bleeding.—Either arteries or veins may be cut and the blood thus permitted to escape. Arterial blood is recognized by its spurting. Venous bleeding is usually a slow oozing. In case an artery is injured, it is not sufficient to apply a bandage over the point of injury, but the artery must be compressed at some point where it lies over a bone so that the pressure may be sufficient to close it against the blood pressure. Pressure may be applied by means of a pad of

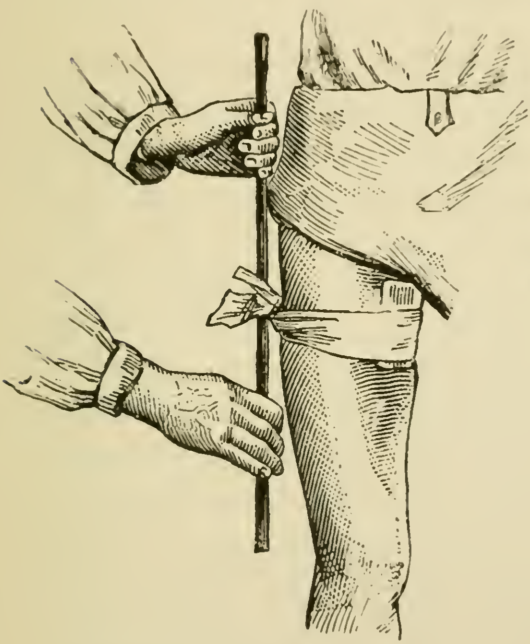

Fig. 148.—Compression of artery in leg.

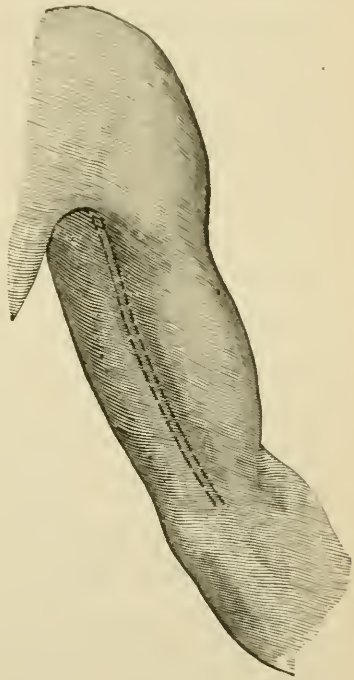

Fig. 149.—Compression of femoral artery.

cloth, a smooth stone or other object bound tightly over the spot. The chief points of pressure for arteries are as follows: 1) behind the knees; 2) the inner side of the thigh (Fig. 148); 3) the inner border of the biceps muscle in the upper arm (Fig. 149).

For bleeding from veins and ordinary slight cuts, a light pressure by a pad over the point of injury is sufficient.

Bleeding from the nose suggests trouble with the mucous membrane lining the nasal cavity, and if habitual should receive the attention of a physician. Profuse bleeding may necessitate the application of dilute solutions of tannin or alum; if these are not successful, the nose should be plugged by a physician.

Bleeding from the lungs and stomach occurs at times, but is seldom fatal. Rest and quiet are essential.

Bruises and Sprains.—Apply hot water or rub vigorously with fingers.

Antiseptic Treatment of Wounds.—"Catching cold" in a wound means the entrance of bacteria and consequent inflammation. After carefully washing the hands with soap and hot water, wash the wound thoroughly with a solution of carbolic acid (3%), a solution of corrosive sublimate (1 to 1000), or a solution of formalin (1 to 40). If you do not have these, use strong alcohol, whiskey, brandy or boiled water. Then bring the edges of the wound together, hold in place by a compress of baked clean cloth, and bind tightly with a bandage. If treated in this way, the wound will ordinarily heal "by first intention," and need not be disturbed.

Burns and Scalds.—If slight, apply a paste of cooking soda or alum. If extensive, apply Carron oil (equal parts lime water and linseed oil). When a burn covers a quarter of the surface of the body, it should be regarded as very serious, possibly fatal, and a physician should be summoned immediately. Apply vaseline, Carron oil, etc., or put into bath tub with warm water to which a cup or two of salt has been added. Keep the water at a temperature of 90° to 100° F. Watch the strength carefully and give stimulants, as strychnia, coffee, alcohol, ammonia, etc., as needed.*

* When a person's clothing takes fire, roll him in wet cloths, woollen

Pain.—Apply heat, as hot water bottle, etc., or mustard plaster.

Stings of Insects.—Apply ammonia or soda.

Snake Bite.—Do not give large amounts of alcohol. Suck out the poison or cauterize the wound immediately, or tie a string tightly around the limb above the point of injury to prevent carrying the poison into the system. Use stimulants, as ammonia, coffee, alcohol, if necessary.

Poisoning by Canned Foods, Ice Cream, Salads, etc.—Give an emetic, and castor oil to clear out bowels.

Foreign Body in Eye.—Take a small pencil or stick and press upon the middle of the upper part of the eyelid, at the same time raising the lid by means of the eyelashes with the other hand. Press down the cartilage of the lid until its edge swings below and exposes the inner surface. Find the object and remove by making a soft moistened point of a handkerchief. When no assistance can be obtained avoid rubbing the eye, grasp the eyelashes and hold away from the eye to permit the tears to wash the object from beneath. One or two drops of a 2% solution of cocaine may be put into the eye to allay the pain after the object is removed or the pain of an object which cannot be removed. Persistent aching and redness of one eye usually means irritation by a foreign body.

Frost Bite.—When a part of the body is frozen it should be rubbed with *melting* snow, ice or ice water. As soon as the blood returns apply cracked ice to reduce the reaction.

clothing, rug or carpet, or put out the fire with water, sand, ashes or other non-burnable material. If nothing is at hand, pull off burning clothing or roll him over and over to crush out the flame. When in a burning building where the smoke is thick, keep the head near the floor. If no escape is possible, get upon the outside of the window-sill and close the window.

Contagious Diseases.—Since contagious diseases are all probably due to bacteria, washing serves to remove them from the person, and hence aids to avoid infection. When one comes in contact with a sick person he should touch him only with the hands and then wash them with warm water and soap immediately afterward, to avoid contaminating door knobs and articles of furniture which others are liable to touch. It is better to try to avoid all diseases, even whooping cough, measles and mumps, since they are never without possibilities of danger.

Tuberculosis (consumption) must be considered as one of the contagious diseases and should be guarded against by isolation or rigid cleanliness, including the destruction of all sputum by burning or with strong antiseptics.

A person who has a contagious disease should be immediately isolated from every one except a nurse, and the nurse should also be isolated. All articles of food or clothing coming from the room should be burned or disinfected.

Most contagious diseases are acquired by transferring the bacteria from objects on which they have been deposited to the mouth, by taking infected food, as milk or water, or by inhaling them as dust. All suspicious food and water should be well cooked or boiled before it is used.

Disinfection.—All unnecessary articles of furniture, draperies, cushions, etc., should be removed from a room to be occupied by a person with a contagious disease. Articles of furniture and clothing which have come in contact with the patient directly or indirectly should be either destroyed by burning, or disinfected by boiling, or soaking thoroughly in a strong antiseptic solution, such as carbolic acid or formalin. The room should be disinfected by the fumes of formaldehyde generated from a solution of formalin (one liter of

formalin to 1000 cubic feet of air space). Windows and doors should be tightly closed and sealed.

Disinfectant Solutions:

Milk of lime—one part of fresh lime to five parts of water. Stir before using. This may be used for discharges in typhoid, cholera, etc., and should be mixed with them in sufficient amount to make them strongly alkaline. After standing a half hour they may be thrown into privy or sewer. Whitewashing with a freshly made solution is an effective treatment for nearly all forms of bacteria.

Chloride of lime—one pound to two and one half gallons of water. This may be used for excreta.

Fumigation by sulphur is comparatively valueless. Sunlight is effective for surface disinfection only. Ventilation cannot remove all disease germs. Dusting and beating of garments merely serve to scatter the germs and endanger the individual who does the beating.

APPENDIX B.

THE ACTION OF ALCOHOL AND TOBACCO UPON THE HUMAN BODY.

Introductory.—We have already seen (p. 98) that alcohol is not to be regarded as either a tissue-forming or a force-giving food.

By causing a transference of heat from internal parts to the skin, in which the main organs of the temperature sense (p. 283) are located, it produces a temporary feeling that the body is warmer; but the final result is a loss of animal heat to the air, and a decrease of the temperature of the body as a whole. Experiments made on men under military regimen and discipline have proved that alcohol does not increase the power of sustained muscular work, though it may for a brief time stimulate to unhealthy activity. The relative amount of energy liberated in the body for its own use may be very fairly calculated by comparing the amount of oxygen absorbed by the lungs on one day with the amount absorbed on another. We have learned that on the days when alcohol is taken the oxygen absorbed is not increased. Alcohol seizes some of the oxygen which the foods and tissues would have utilized in its absence; and what it takes they lose. Most authorities even maintain that alcohol prevents oxidation, and therefore tissue activity, indirectly as well as directly; these experi-

menters find that it not only takes oxygen from the tissues, but so influences them as to diminish their power of using what it leaves. We may conclude that under ordinary circumstances alcohol is of no use as an energy-yielding food; although, since it is oxidized in the body, it would act as a real food to a starving man; or to a very sick person who might be unable for the moment to absorb and digest other substances.

As regards tissue-formation, alcohol cannot build up proteid material, since it contains no nitrogen; and proteid material constitutes the essential part of muscular, glandular, and nervous tissues. There is even some evidence that alcohol leads to excessive waste of such tissues: several competent observers have found that its use increases the amount of nitrogen waste excreted from the body. The only tissues whose formation alcohol seems sometimes to increase are fatty and connective tissues; and we shall presently learn that in most cases the superabundance of these tissues is deposited in places where it does harm.

The study of alcohol as an article of diet leads therefore to the result that (though a physician may find it useful as a medicine in a crisis of disease when the system needs urging to make a special effort) it cannot fairly be regarded as a food when taken by persons in good health and properly nourished.

The whip applied to a horse will arouse him to call on his reserve force, and perhaps carry himself and his rider safely past some point of special danger; but it does not in any way nourish the horse. As regards the healthy human body alcohol may be compared to a whip: an amount of it not sufficient to cause drunken sleep, temporarily excites various organs; but the consequence is subsequent greater exhaustion.

So far we have learned that alcohol as a regular article of

diet is, at least, useless. Were that all, we might regret the annual waste of corn, barley, wheat, and fruits in its production, and think the man foolish who spent his money on it. In such case the matter would be one for moralists and political economists to deal with, and physiologists and students of hygiene might leave it alone. Unfortunately, alcoholic drinks are not merely useless but positively hurtful, when taken regularly, even in what is usually called moderation. Alcohol has probably caused in the past, and is certainly causing at present in civilized nations, more disease and death than either bad drainage, bad ventilation, overcrowding, deficient food, overwork, or any other of the conditions prejudicial to health concerning which Physiology and Hygiene warn us. The moral degradation and the physical condition of the drunkard speak for themselves; it is therefore the more insidious consequences of alcohol-drinking that we shall mainly describe.

Alcohol, when pure, is a transparent colorless liquid, containing the elements carbon, hydrogen, and oxygen (C_2H_6O); it is lighter than water, and boils at a considerably lower temperature; is highly inflammable, burning with a bluish flame; and is the essential constituent of all fermented liquors in common use.

Alcoholic Beverages include (1) *malt liquors,* as beer, ale, stout, and porter; (2) *cider* and *perry;* (3) *wines,* as claret, sherry, port, champagne, and catawba; (4) *distilled spirits,* as brandy, rum, and whiskey; and their compounds, as gin, cherry brandy, pineapple rum, and so forth; (5) *liqueurs,* made by adding various flavoring essences to different kinds of spirits. All contain alcohol in greater or less proportion, varying from over 70 volumes in the 100 in some kinds of rum to less than 2 in the 100 in "small" beer.

The Direct Physiological Action of Pure Alcohol.—Pure alcohol is a very expensive substance, mainly employed in chemical experiments and in the manufacture of certain perfumes and essences. However, some clues to the action of diluted alcohol on the body may be obtained by a study of its action in the concentrated form.

Strong alcohol having a great tendency to combine with water, rapidly extracts that substance from any animal organ placed in contact with it; as is shown by the hardening and shrivelling of museum specimens placed in it.

Added to raw white of egg it coagulates it, much as if the egg had been boiled: added to fresh blood it acts in a similar manner, coagulating the serum albumin as heat does (p. 155).

Pure alcohol placed on the skin evaporates very rapidly, and in so doing abstracts heat (p. 226, *note*), producing a sensation of coolness. This is succeeded by a feeling of warmth in the part, which also becomes red from temporary paralysis of its blood vessels, causing them to dilate. If the evaporation be prevented, as by putting a little alcohol on the skin and covering it with a thimble, the alcohol acts as an irritant; it causes smarting, and finally sets up inflammation.

On mucous membranes alcohol acts much as on the skin, but its irritant effect is more marked. Placed on the tongue it causes a feeling of coolness, followed by a hot, biting sensation, and a red congested condition of the area with which it came in contact. Introduced into the stomach of a rabbit or dog, where it cannot readily evaporate, strong alcohol causes congestion and inflammation varying in intensity with its amount. If the dose is large the animal dies almost instantly, because the powerfully irritated sensory nerves of

the gastric mucous membranes reflexly excite a nerve centre which stops the heart's beat.

Diluted Alcohol does not produce the above-described direct actions of the pure liquid : this latter taken into the stomach acts as a powerful irritant poison, and generally produces its main effects on the stomach itself. Alcohol in such proportion as it exists in most alcoholic drinks exerts much less local action on the gastric mucous membrane ; but it is absorbed and carried in the blood and lymph through the body, and if steadily taken day after day acts upon and alters for the worse nearly every important organ. The organ first or most seriously attacked varies with the form in which the alcohol is taken, with the amount consumed daily, and with the constitution of the individual. Probably no one individual ever suffered from all the diseased states produced by alcohol described in the following pages ; but habitual drinkers are very apt to experience one or more of them. The diseases produced by alcohol after absorption into the blood come on so gradually (except in the case of obvious drunkards) that the victim rarely perceives them until serious if not irremediable damage has been done : indeed, physicians have only recently come to clearly recognize that men who in common phrase "were never in their lives under the influence of liquor" may nevertheless be drinking enough to do them grave injury.

Absorption of Alcohol.—When alcohol (so diluted as not to cause active inflammation of the stomach) is swallowed, it is quickly absorbed by the capillary blood vessels of the gastric mucous membrane.* These pass it on to the portal

* An exception to the rapid absorption of alcohol sometimes occurs when a large quantity of raw spirits is taken. Many cases are recorded where men have for a wager drunk a bottle of whiskey or brandy. The

vein, which carries it (p. 177) direct to the liver. Collected from the liver by the hepatic veins, it is conveyed through the inferior vena cava to the right auricle of the heart. Thence it passes on in the general blood flow (pp. 167, 168, 177) to right ventricle, lungs, left auricle, left ventricle, aorta, and by branches of the aorta to the body in general: to the heart muscle (by the coronary arteries, p. 169), to the brain and spinal cord, to the muscles, to the kidneys, to the skin. We have to study its action on all these organs.

The Primary Effects of a Moderate Dose of Diluted Alcohol, as a glass of whiskey and water, on one unaccustomed to it, are to cause temporary congestion of the stomach; dilatation of blood vessels of the skin, indicated by the flushed face; a more rapid and forcible beat of the heart;* nervous excitement, exhibited by restlessness and talkativeness. Then some incoherence of ideas, and often giddiness. Finally there is a tendency to sleep. On awaking the person has some feeling of depression, not much appetite, and is in general a little out of sorts for a day.

If the dose be larger the stage of giddiness is accompanied by diminution of the sensibility of the skin, and imperfect control over the voluntary muscles, indicated by defective articulation and a staggering gait. The muscles moving the eyeballs cease to work in harmony. Normally they act unconsciously, turning the eyes so that images of objects looked at are focused on corresponding points of the retinas, and objects are seen single. Soon after the voluntary move-

result is often sudden death, but sometimes no effect is noticed for fifteen or twenty minutes; then there is a sudden unconsciousness, passing into stupor, which ends in death. In such cases the large quantity of strong spirits seems temporarily to paralyze the absorbing power of the stomach.

*It is doubtful if chemically pure alcohol diluted with water quickens the pulse; most ordinary alcoholic beverages, however, undoubtedly do.

ments are affected the involuntary regulation of the eye-muscles is impaired, and objects are seen double, the eye-balls being no longer so turned as to bring images on corresponding retinal points. The stomach may also be so irritated as to lead to vomiting. Then comes deep drunken sleep; followed by headache, loss of appetite, and prostration similar to, but more marked than, that occurring after the smaller dose.

If the alcoholic indulgence be repeated, day after day, some of the above-described primary consequences become less marked; but they give way to more serious functional and structural diseases.

The Secondary Effects of Alcohol vary much in intensity with the form in which it is taken; also, no doubt, with the constitution of the person taking it, and with the length of time during which he has been drinking. We shall consider them in three groups: I. Comparatively slight and curable diseased states due to what is commonly considered moderate drinking. II. Severe acute alcoholic diseases. III. Chronic and usually incurable morbid states, due to steady, prolonged drinking; these fall into three main subdivisions: *a*. General tissue deterioration; *b*. Destruction, more or less complete, of certain organs; *c*. Deterioration of mind and character.

I. Minor Diseased Conditions produced by Moderate Drinking.—Of these, *alcoholic dyspepsia* is the most frequent. A vast number of persons suffer from it without knowing its cause, people who were never drunk in their lives, and consider themselves very temperate. "The symptoms vary, but when slight are something like these: A man (or woman) complains of slight loss of appetite, especially in the morning for breakfast; feels languid either on rising or early in the

day; retches a little in the morning, and perhaps brings up a little phlegm only, or may actually vomit; or may be able to take breakfast, but feels sick after it. Towards the middle of the morning he is heavy and languid, perhaps, and does not feel easy until he has had a glass of sherry or some spirits; then gets on pretty well, and can eat lunch or dinner. Or if worse, the appetite for both is defective, and there is undue weight or discomfort after meals. . . . Now all these symptoms *may* be due to other causes, but when taken together they are by far most commonly due to alcohol." *

Another frequent result of regular "moderate" drinking is *tremor*, or shakiness of the hands. The hand is unsteady when the arm is folded, and is seen to tremble if it be held out with the arm extended. This tremor is very marked in the alcoholic disease known as *delirium tremens* (p. 335). Even in its simple form it interferes with the performance of any action calling for manual dexterity. The trembling may, in most cases, be stopped for a time by an extra glass; and thus often leads to the acquirement of more serious diseases.

We class the above as minor diseased conditions, because in most cases they occur before the will power is seriously impaired, and abstinence from alcohol is soon followed by recovery.

II. Acute Alcoholic Diseases.—A single large dose of alcohol, or the repetition of small doses at short intervals, ends in a fit of drunkenness.

The disgusting appearance of a drunken man, the loathing which he excites even in those most attached to him, the loss of control over his actions, which makes him the prey of criminals, or, yet worse, a criminal himself, taken together

* Dr. Greenfield, in "Alcohol: its Use and Abuse."

make a picture to which the physiologist need add nothing. A man not deterred by its contemplation will not be hindered in the indulgence of his appetite by any argument based on injury to his health.

Delirium Tremens.—Repeated drunkenness usually ends in an attack of *delirium tremens*, but this disease is more frequently the result of prolonged drinking which has never culminated in actual drunkenness. It is especially apt to occur in "those who drink hard, but keep from actual loss of consciousness, especially those engaged in hard mental work or subjected to great moral strain or shock; and, too, those of certain temperaments are peculiarly liable to it. It is preceded, usually, by loss of sleep, ideas of persecution or injury, with no foundation in fact, and slight hallucinations, especially at night; the man, meanwhile, in the day looking anxious, slightly excited, nervous and tremulous, and perhaps narrating as actual occurrences the hallucinations of the preceding night. Then the senses are partly lost; he sees spectres, horrible and foul creatures about him; has all sorts of painful, terrifying visions (whence the common name of the 'horrors'); is extremely tremulous, and either excited or lies prostrate, trembling violently on movement, sleepless, anxious, and a prey to spectres and terrors of the imagination." *

Few persons die in their first attack of delirium tremens, but it is nature's unmistakable warning to the tippler; let him not disregard it, unless he is prepared to die without hope in maniacal imaginings so frightful that those around his death-bed can never recall the scene without horror!

Dipsomania is often confounded with delirium tremens; but though it may lead to that disease it is an essentially

* Dr. Greenfield, in "Alcohol: its Use and Abuse."

different pathological state. The word properly means a mental disease in which there is periodically an irresistible passion for alcohol; in any form, no matter how distasteful, the dipsomaniac will swallow it with avidity. The disease is sometimes produced by indulgence in drink, but is more often inherited, especially from parents addicted to alcoholic excess. In the families of such, one child is often epileptic, another idiotic, a third eccentric or perhaps quite mad, and a fourth a dipsomaniac. When the fit seizes him the dipsomaniac is as irresponsible as a raving madman. His only safeguard against a frightful debauch is to place himself under restraint as soon as he perceives the symptoms which he has learned to recognize as premonitory of his fit of madness. After a time the paroxysm passes off; the patient regains self-control, loses his passion for drink, is greatly ashamed of himself if he has indulged it, and usually behaves in an irreproachable manner for some weeks or months.

The sufferers from this frightful disease are entitled to a sympathy to which the common drunkard has no claim.

III. Chronic and often Incurable Diseased Conditions produced by Alcohol.—These are apt to be insidious in their approach, and overlooked until they have firmly seated themselves. They include (*a*) deterioration of tissue; (*b*) practical destruction of important organs; (*c*) mental and moral enfeeblement.

(*a*) **Deterioration of Tissue due to Alcohol.**—A serious structural change in the body produced by alcoholic excess is *fatty degeneration*. The oily matter of the body exists in two forms: first, as adipose or fatty tissue collected under the skin, and in less amount elsewhere, as on the surface of the heart and around the kidneys; second, as minute fat-droplets in the interior of various cells and fibres. Some

forms of alcoholic drinks tend to increase the adipose tissue, and may lead to undue accumulation of it about the heart, impeding the action of that organ. A more important and frequent result is an increase of fat-droplets in the cells of the liver and the muscular fibres of the heart, the oily matter replacing the natural working substance. A heart which has undergone this change is commonly spoken of by pathologists as a "whiskey heart"; for although fatty degeneration of the heart may occur from other causes, alcoholic indulgence is the most frequent one. Fatty liver or fatty heart is rarely if ever curable; either will ultimately cause death. It is probable that in both cases the fatty degeneration is due to over-stimulation of the organ. Most wines and spirits quicken the beat of the heart, leaving it less time for repair between its strokes. Alcohol also increases the breaking down of proteid matter in the body; the liver has much to do in preparing this broken-down proteid for removal by the kidneys, and so gets overworked.

Another serious bodily deterioration produced by alcohol is *fibrous degeneration*: by this is meant an excessive growth of the connective tissue, which, as we have seen (p. 18), pervades the organs of the body as a fine supporting skeleton for the more essential cells. Alcohol-drinking causes this tissue to develop to such an extent as to crush and destroy the cells, especially in the liver and kidneys, which it should protect. So far as the liver is concerned, the result is a shrunken, rough mass (*hob-nailed liver*, or *gin-drinker's liver*), with hardly any liver cells left in it. This not only prevents the proper manufacture of bile and glycogen (p. 130), but the contracted liver presses on the branches of the portal vein within it (p. 177) so as to impede the drainage of blood from the organs in the abdomen. As a consequence, an excess of

the watery part of the blood oozes into the peritoneal cavity and accumulates, causing abdominal dropsy (*ascites*). In similar manner the superabundant connective tissue in the kidneys crushes and injures the essential kidney substance, and interferes with the proper function of the organ in excreting nitrogen waste and water. The ultimate consequence is one form of "Bright's disease"—a very fatal malady, characterized by elimination of albumen in the kidney secretion; retention of proteid wastes in the blood, poisoning the various organs; and accumulation of water in the loose tissue binding the skin to underlying parts, producing that kind of dropsy known as *anasarca*.

(*b*) **The Organs of the Body most apt to be impaired or destroyed by Alcohol** have been in part mentioned in preceding pages. It will, however, be convenient to collect them together and point out the kind of change produced in each. Probably no tippler ever suffered from all of these diseases, and most of them may develop in persons who are total abstainers; but the organic lesions which are mentioned below are more frequently due to intemperance than to any other cause.

A primary action of alcohol after absorption is to cause dilatation of the cutaneous blood vessels. With occasional alcoholic indulgence this is temporary; with repeated, it becomes permanent. **The Skin** is then congested and puffy, and on exposed parts it is seen to have a purplish or reddish blotched appearance; pimples appear on parts, such as the nose, where the natural circulation is more feeble. The result is the peculiar degraded look of the sot's face. The congestion interferes with the nutrition of the skin; the epidermis (p. 200) is imperfectly nourished and collects in scaly masses,

interfering with the proper action of the sweat glands, thus throwing undue work on the kidneys.

When constantly irritated by the direct action of strong alcoholic drinks, **the Stomach** gradually undergoes lasting changes. Its vessels remain dilated and congested, its connective tissue becomes excessive, its power of secreting gastric juice diminished, and its mucous secretion abnormally abundant.

The Liver suffers fatty and fibrous degeneration, and is one of the organs most often and earliest attacked. This we might expect, as all the alcohol absorbed from the stomach is carried direct to the liver by the portal vein (p. 177).

The Heart has its walls at first thickened (*hypertrophied*) and its cavities dilated by the excessive work (p. 337) which alcoholic drinks stimulate it to perform. If, as is usually the case, fatty degeneration ensues, the organ gradually becomes too feeble to pump the blood around the body, and death results.

The walls of **the Arteries** of drinkers frequently undergo fatty degeneration; they lose their strength and elasticity, and are liable to rupture, or to the disease known as *aneurism*.

The Kidneys are excited to undue activity, in part by the dilatation of their blood vessels, in part, perhaps, through direct stimulation of their cells by alcohol circulating in the blood. Once the liver is attacked the nitrogenous waste of the body is not carried to the kidneys in proper form for excretion: some is held back, producing a tendency to *gout* and *rheumatism;* the rest is got rid of by extra kidney effort. The usual result is fibrous degeneration of the kidneys, causing one kind of Bright's disease.

The Lungs, from the congested state of their vessels pro-

duced by alcohol, are more subject to the influence of cold, the result being frequent attacks of *bronchitis*. It has also been recognized of late years that there is a peculiar form of consumption of the lungs which is very rapidly fatal, and found only in alcohol-drinkers.

The Sense Organs are also affected ; their acuteness of perception is dulled, and many physicians believe that *cataract* and retinal disease may be produced by drinking. The red inflamed white of the eye of topers is well known.

The Brain and Spinal Cord are kept in a chronic state of congestion* and over-excitement. This results at first in inflammatory disease (*delirium tremens*) ; later, in fibrous degeneration, leading to certain forms of paralysis or to *epilepsy*, of which there is one variety well recognized by physicians as due to alcohol.

(*c*) **Moral Deterioration produced by Alcohol.**—One result of a single dose of alcohol is that the control of the Will over the actions and emotions is temporarily enfeebled ; the slightly tipsy man laughs and talks loudly, says and does rash things, is enraged or delighted without due cause. If the amount of alcohol be increased, further diminution of will-power is indicated by loss of control over the muscles. Excessive habitual use of alcohol results in permanent over-excitement of the emotional nature and enfeeblement of the Will ; the man's highly emotional state

* "I once had the unusual though unhappy opportunity of observing the same phenomenon in the brain structure of a man who, in a fit of alcoholic excitement, decapitated himself under the wheel of a railway-carriage, and whose brain was instantaneously evolved from the skull by the crash. The brain itself, entire, was before me within three minutes after death. It exhaled the odor of spirit most distinctly, and its membranes and minute structures were vascular in the extreme. It looked as if it had been recently injected with vermillion."—*Dr. B. W. Richardson.*

exposes him to special temptation to excesses of all kinds, and his weakened Will decreases the power of resistance: the final outcome is a degraded moral condition. He who was prompt in the performance of duty begins to shirk that which is irksome; energy gives place to indifference, truthfulness to lying, integrity to dishonesty; for even with the best intentions in making promises or pledges there is no strength of Will to keep them. In forfeiting the respect of others respect for self is lost and character is overthrown. Meanwhile the passion for drink grows absorbing: no sacrifice is too costly which secures it. Swift and swifter is now the downward progress. A mere sot, the man becomes regardless of every duty, and even incapacitated for any which momentary shame may make him desire to perform.

For such a one there is but one hope—confinement in an asylum where, if not too late, the diseased craving for drink may be gradually overcome, the prostrated Will regain its ascendency, and the *man* at last gain the victory over the *brute*.

Tobacco contains an active principle, *nicotin*, which in its pure form is a powerful poison, paralyzing the heart. When tobacco is smoked some of the nicotin is burned, but there are developed certain acrid vapors which have an irritant action on the mouth and throat. The effects of smoking are thus in part general, due to absorbed nicotin; and in part local, due to irritant matters in the smoke. They vary much with the constitution, habits, and age of the smoker. One general rule at least may be laid down: *tobacco is very injurious to young persons whose physical development is not completed.*

The Local Action of Tobacco is at first manifested by increased flow of saliva. This usually passes off after some

practice in smoking; dryness of the mouth follows, and consequent thirst, often leading to alcoholic indulgence; and in this, perhaps, lies the greatest danger from tobacco. The habitual smoker usually suffers eventually from what is known to medical men as "smoker's sore-throat." The inflammation often extends to the larynx, injuring the voice and producing a hacking cough, or may spread up the Eustachian tubes (p. 279) and impair the hearing. Cigarettes are especially apt to cause these symptoms. Cure is impossible unless smoking be given up. Those who draw the smoke into their lungs often suffer from chronic inflammation of the bronchial tubes in consequence.

The General Action of Tobacco.—The more common effects of absorption of tobacco products are to interfere with development of the red blood-corpuscles, leading to pallor and feebleness; to impair the appetite and weaken digestion; to affect the eyes, rendering the retina less sensitive; to cause palpitation of the heart and enfeeblement of that organ; to induce a lassitude and indisposition to exertion that, in view of the heavy odds man has to contend with in the life-struggle, may prove the handicap that causes his failure. If success in life be an aim worth striving for, it is surely unwise to shackle one's self with a habit which cannot promote and may seriously jeopardize it.

APPENDIX C.

DEMONSTRATIONS AND EXPERIMENTS.*

BONES.

Materials : Hind leg of sheep sawed lengthwise through the joints. Pieces of fresh ivory bone (thin bones such as are found in the legs of fowl will answer). Pieces of dry ivory bone.

Reagents : Hydrochloric acid (HCl) and ammonia.

Apparatus : Balance with metric weights from 1 centigram to 25 or 50 grams. The balance may be a small hand balance carefully adjusted.

Human skeleton (such as may be purchased for $25 or $30).

Microscope.

Dissection or Demonstrations :

To be done preferably by pupils working together in pairs with specimen.

1) Structure of a long bone.

a) Position and arrangement of dense (ivory) and cancellated bone.

b) Medullary canal.

c) Joint ends with epiphyses.

d) Articular cartilage.

* The practical work is planned to include that given in the Outline of Requirements in Anatomy, Physiology and Hygiene for Admission to Harvard College and the Laurence Scientific School.

e) Periosteum.

f) Red and yellow bone marrow.

g) Microscopic structure of bone.

2) Composition of bone.

a) Boil a piece of fresh bone in water to extract gelatin.

b) Burn a piece of fresh bone to destroy animal matter.

c) Put piece of fresh bone into solution, one part hydrochloric acid, four parts water (let stand one or two days and if necessary change the solution) to remove mineral matter.

Experiments :

1. Proportions of water and solid in fresh bone. Break piece in small fragments, weigh, dry in a current of warm air to constant weight and determine loss.

2*a*. Proportions of animal and mineral matter in dry bone. Weigh, burn on a piece of sheet iron over live coals or on a piece of platinum foil over Bunsen burner and weigh.

2*b*. Second method. Weigh, dissolve in 10% hydrochloric acid, dry to constant weight and determine loss.

NOTE.—Demonstrate the presence of mineral matter in the solution by precipitating it with ammonia.

JOINTS.

Materials : Split joint of sheep.

Apparatus : Microscope.

Dissection or Demonstrations :

a) Capsular and reinforcing ligament.

b) Synovial membrane.

c) Synovial fluid.

d) Articular cartilage.

e) Functions of ligaments.

MUSCLE.

Material : A frog.

A slice of meat cut across the grain (a low cut of the leg including the bone).

Normal salt solution, made by dissolving 7½ gms. of dried table salt in 1 liter of water.

Dissection or Demonstrations :

1) Uncover muscles in frog's leg. Note

a) Outlines of muscles.

b) Tendon attachments.

c) Relations of muscles to joints.

2) In piece of beef, note

o) Muscle bundles.

b) Connective tissue boundaries of muscles and bundles.

c) Surface or intermuscular tendon, if present.

3) Prepare muscle fibre by plunging a freshly killed frog into water at 55° C. (131° F.) and allowing it to cool.

a) Tease muscle with needles in normal salt solution.

b) Examine under microscope.

Experiment : Proportions of water and solid in muscle. (Determine as in bone (1).

MUSCLE ACTION.

Materials : Calf muscle of leg of frog with sciatic nerve attached (nerve-muscle preparation).

Apparatus : Induction coil, battery and wires. A small coil such as is used by physicians will answer the purpose.

Recording apparatus (Fig. 150).

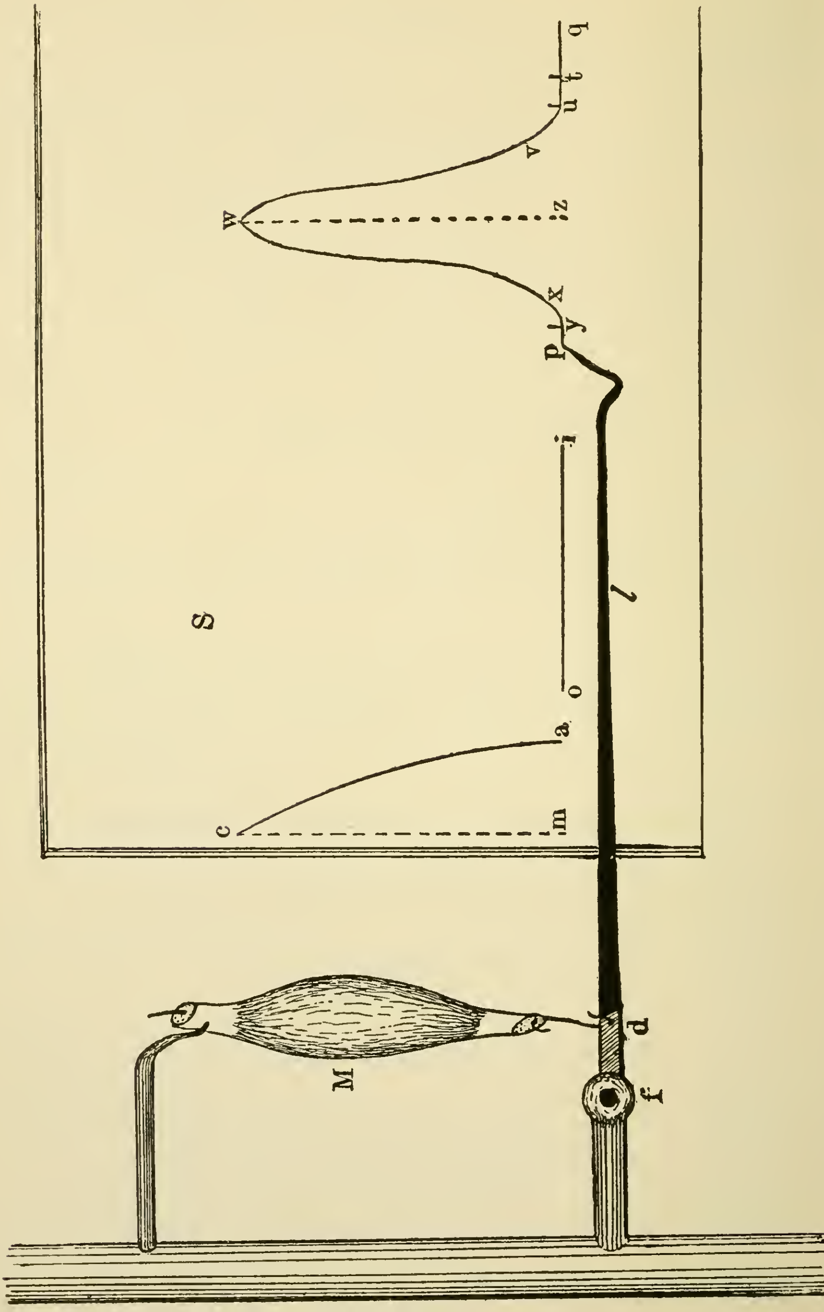

Fig. 150.—Diagram to illustrate the method of obtaining a graphic record of a muscular contraction. *M*, muscle from frog (nerve is not shown); *l*, lever hinged at *f* and with writing point at *p*. *S*, piece of smoked glass to be moved along in front of the writing point of lever.

Experiments (or Demonstrations) :

What results follow

a) Single electrical shock through nerve?

b) Single electrical shock through muscle?

c) Rapid succession of shocks through nerve? "Tetanus."

Demonstrations :

1) Contraction curve.

2) Curve of fatigue.

a) Regular stimulation at intervals of one second.

b) Tetanus.

Directions :

For the contraction curve, the smoked glass should be moved so that the distance between the rise and fall of the writing point will be one or two inches.

For the curve of fatigue, the smoked glass should be moved between each contraction just enough to allow the next contraction to make its own record. For tetanus, a slow, continuous movement is necessary. The rapid interruption of the current necessary for tetanus can easily be accomplished by tapping the end of one wire on a piece of tin connected with the other, if no key is available.

LEVERS.

The leverage conditions in the body may best be studied by means of an apparatus arranged to represent the action in several joints (Fig. 151).

Apparatus : Lever apparatus.

Problems to be experimentally solved with the lever apparatus.

1) Apparatus arranged to represent action of biceps.

a) How much force must the biceps exert to hold a

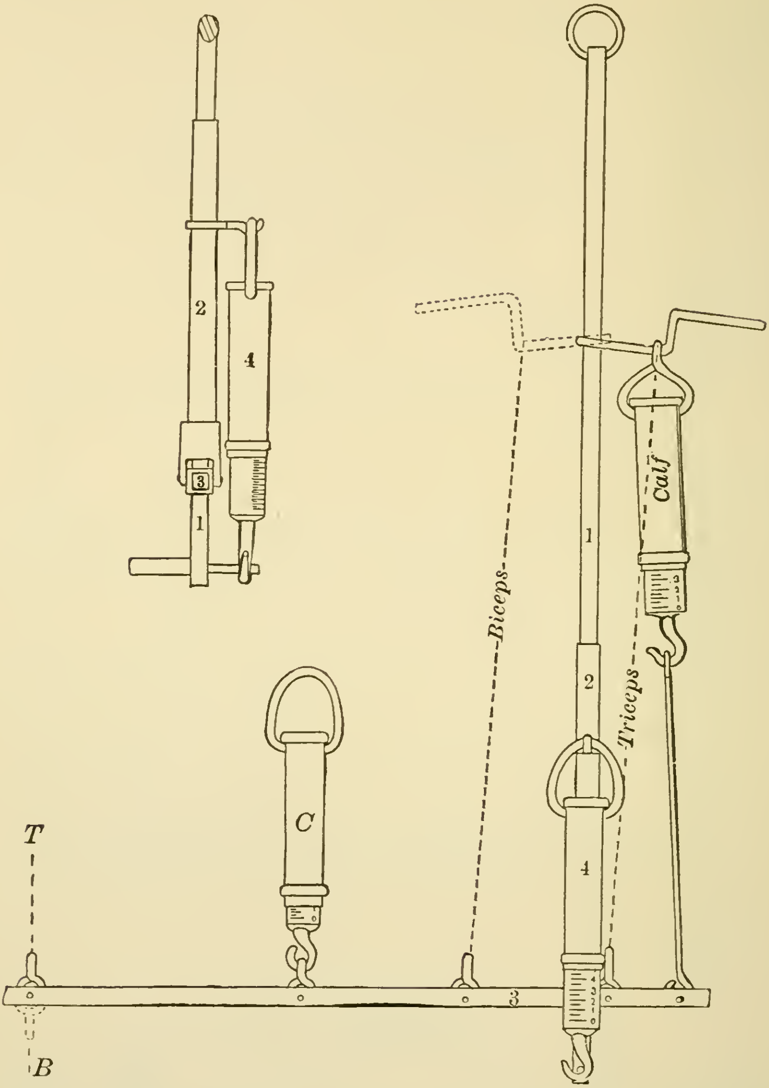

FIG. 151.—Lever apparatus for studying the mechanics of muscles, bones, and joints—shown as arranged for the study of forces in the calf muscles and ankle joint. The larger figure shows two connected bars, 1 and 3: (1) represents either the bones of leg or upper arm, and (3) those of the foot or arm. Another view of the joint is shown in smaller figure. A brass sleeve (2) having at its lower end the joint with the brass cross-arm (3) slips easily on the rod (1) and forms a part of it. The joint pressure is measured by the spring scale (4) which resists the pressure of arm (3) upon the hinge and sleeve. The spring scale labelled "calf" represents the calf muscle, the biceps muscle, or the triceps muscle, and measures the force each is made to exert according as it is attached as represented or in the position of one or the other of the dotted lines. The pull may be made greater or less by moving the upper attachment up or down the rod (1). The spring scale (*c*) measures the effective force of the calf muscles in the position shown and may be changed to (*B*) and (*T*) for measuring the effective forces of the biceps and triceps muscles of the arm respectively.

pound weight in the hand when the elbow forms a right angle and the forearm is horizontal?

b) How much is the pressure in the joint under the same conditions?

2) Apparatus arranged to represent action of triceps.

a) How much force must the triceps exert to make the hand push one pound?

b) How much is the pressure at the elbow joint?

3) Apparatus arranged to represent action of muscles of calf of leg.

a) When a person of 150 lbs.* weight is standing on one foot, how much force must the calf muscles exert to raise the heel from the floor?

b) How much is the pressure in the ankle joint?

Problems to be solved arithmetically. Each pupil should use his own weight and make the necessary measurements on himself or on a skeleton.

1. *a*) How much force do the calf muscles exert in raising the heel from the floor when standing on one foot?

b) How much is the pressure in the ankle joint?

2. *a*) How much is the muscle pull through the patella to raise the body from a kneeling posture (the whole weight on one leg)?

b) How much is the pressure in the knee joint?

3. *a*) How much does the biceps pull when, by flexing the forearm, 50 lbs. are raised in the palm of hand?

b) How much is the pressure in the elbow joint?

* Use 1.5 lbs. on balance to represent the 150 lbs.

OXIDATION.

Materials : Magnesium tape.
Fine emery paper.
Fine iron wire.
Oxygen.
Sulphur.

Demonstrations or Experiments :

1) Rub magnesium tape clean with emery paper. Cut off two pieces.
   a) Apply a lighted match to one ; note manifestations of energy and changes (magnesia) in magnesium.
   b) Place the other in a bottle with a few drops of water ; examine in a day or so, and compare with 1) *a*.
2) Attempt to burn magnesia obtained from 1) *a*.
3) Rub the iron wire bright with emery paper.
   a) Place some in a warm dry bottle by the stove.
   b) Place some in a bottle containing a little water, and in a day or so compare results with those from 3) *a*.
4) Melt a drop of sulphur on end of iron wire. Ignite and plunge into a bottle of oxygen.
   a) Note manifestations of energy.
   b) Note changes in iron and compare with 3) *b*.

FOODS.

Materials : Starch. Dextrin. Glucose. Fat. Sweet Oil.
Egg albumin. Cut white of egg repeatedly with scissors, shake with 20 parts water and filter.

Meat juice. 1 lb. meat finely chopped, soaked for 12 hours in four parts of water and filtered.

Peptone, freshly prepared by digesting fibrin or egg albumin in an artificial gastric juice.

Reagents, etc.: Acetic acid (strong vinegar). Nitric acid. Hydrochloric acid. Ammonia. Sodic hydrate. Sodic carbonate. Cupric sulphate.

Thick starch paste, made by boiling ordinary corn starch.

Acid or alkali albumin, made by heating egg albumin with 5% hydrochloric acid or with weak sodic hydrate solution.

Milk.

*Tests for Food Constituents.**

1) Starch and dextrin, dry or (better) in solution with a watery solution of iodine—change of color. This test is most conveniently made with drops of the solutions on a white plate.

2) Glucose, maltose or lactose solution in test tube with half inch strong solution caustic soda and one or two drops of dilute solution sulphate of copper; shake and boil—color or colored precipitate. (Trömmer's test.)

3) Fat.

a) With 1 per cent solution of osmic acid—color; or

b) By dissolving in ether and allowing to evaporate on glass—grease spot.

4) Egg albumin or serum albumin in dilute solution.

a) Heat in test tube—opacity or precipitate; or

b) In contact with strong nitric acid poured care-

* These tests cover the experimental work needed as a preliminary for digestive experiments. The schedule will be found convenient for recording results.

fully and slowly down side of test tube—color or precipitate.

5) Proteid.

a) Boil with strong nitric acid (color); cool and make alkaline with ammonia—color or colored precipitate (Xanthoproteic test), or

b) With strong sodic hydrate solution and one or two drops very dilute copper sulphate—color (biuret test).

6) Peptone. Biuret test—color.

FOOD MATERIALS.

Tests.	Starch.	Dextrin.	Glucose.	Fat.	Egg-Albumin.	Meat Juice.	Peptone.
Heat..........							
Iodine........							
Trömmer......							
Xanthoproteic.							
Biuret........							
Ether.........							

NOTE.—Students may be tested by giving them mixtures of solutions or other food substances to be tested for fat, sugar, proteid, starch, etc. They should be led to study the foodstuffs, as cabbage, beets, fruits, etc., to determine their constituents.* They should also be encouraged to find out the effects of cooking and to report to the class results of experiments at home. The water in which food substances have been boiled may also be studied.

Demonstrations :

1) Effect on thick starch paste of

a) Saliva, a few drops.

b) Pancreatic extract, a few drops of solution.

* Cellulose is not easily demonstrated as a food constituent. It may be sometimes shown under the microscope after soaking thin sections of the substances for a few minutes in a strong watery solution of iodine, washing with water, transferring to dilute sulphuric acid (2 parts acid to 1 part water by volume); mount the sections on the slide in acid solution and examine. If successful, the cellulose is left blue.

2) Effect of neutralizing the acid or alkali albumin by addition of weak sodic hydrate solution or by the addition of weak acid solution. Color with litmus solution in order to determine neutral point.

3) Typical emulsions under a microscope:

   a) Milk.

   b) Oil which has been shaken with solution of pancreatic extract of bile.

Experiments: Typical foodstuffs.

1) Milk.

   a) Determine specific gravity with hydrometer.

   b) Determine reaction by adding a few drops of litmus solution.

   c) 1) Warm milk in small beaker, add drop by drop a dilute solution of acetic acid, constantly stirring, until precipitation (casein and fat); filter; test filtrate by Trömmer's test (lactose).

   2) Dry residue by squeezing it in the fingers, add to a small portion of it an equal amount of ether, allow it to stand a few minutes, put a drop of the ether from it upon a watch glass and allow to evaporate (fat); remove ether from the residue and test latter by the Xanthoproteic test.

2) Flour. Moisten one teaspoonful of flour and tie the dough in a piece of muslin. Knead thoroughly, first in a small vessel containing water, saving the water, and, second, in running water until the water is no longer colored.

   a) Determine what was washed out of dough.

b) Examine the residue (crude glutin) in muslin; observe tenacity; determine the class of food materials to which it belongs.

NOTE.—Other food stuffs may be examined with profit.

ANATOMY OF DIGESTIVE TRACT.

Materials: Sound and diseased natural teeth obtained from a dentist.

Dilute hydrochloric acid.

Rat or cat.

Chloroform.

An inch or two of the small intestine of a recently killed calf.

50% solution of alcohol.

Normal salt solution.

Hand magnifier.

Demonstration:

1) After having soaked the sound teeth in warm water for one or two days and then sawed them in two with a fine fret or scroll saw, examine the structure.

2) Demonstrate the excavations of teeth by decay.

3) Test the effect of an acid, as dilute hydrochloric or vinegar, upon teeth.

Dissection: Kill a rat or cat by chloroform.

1) Dissect away the skin from the whole ventral aspect of the body and note the large salivary glands in the neck region:

a) The posterior gland (submaxillary), rounded and compact, close to the middle line. Raise the submaxillary, and thereby expose its duct, which passes forward to the mouth, into which

it may be followed by separating the halves of the lower jaw.

b) The large gland, composed of several loosely united lobes (parotid), which reaches from the neighborhood of the ear to the submaxillary. Note the duct of the parotid which passes forward over the face to the mouth, near the angle of which it passes in through the cheek muscles.

c) A small gland in front of the submaxillary (sublingual).

2) Remove the muscles, etc., covering the larynx and trachea; cut away the front and side walls of the chest and abdomen; remove larynx, trachea, lungs, and heart.

a) Note the gullet, a slender muscular tube in the neck, and trace it through the chest.

b) Sketch the relative positions of the abdominal viscera before displacing any of them.

3) Turn the liver out of the way and follow the gullet in the abdomen until it ends in the stomach.

a) Note the form of the stomach; its projection (fundus) to the left of the entry of the gullet; its great and small curvatures; its narrower pyloric portion on the right, from which the small intestine proceeds.

b) Notice a thin membrane (the omentum) attached to the stomach, and hanging down over the other abdominal viscera.

4) Follow and unravel the coils of the small intestine, spreading out as far as possible the delicate membrane

(mesentery) which suspends it from the upper dorsal part of the abdominal cavity.

a) Note blood vessels and lacteals running in the numerous bands of fat in the mesentery. (The lacteals are best seen in a cat killed three or four hours after a meal of rich milk.)

5) Open into the side of the large intestine opposite junction with small.

a) Note the termination of the small intestine (ileocæcal valve).

b) Observe the cæcum or blind end of the large intestine, projecting on one side of the point of entry of the small. (Note position of the vermiform appendix in the human body.)

c) Follow the large intestine until it ends at the anal aperture, cutting away the front of the pelvis to follow its terminal portion (rectum).

d) Note the colon, the portion between the cæcum and the rectum.

6) Spread out the portion of the mesentery lying in the concavity of the first coil (duodenum) of the small intestine; and note

a) The pancreas, a thin branched glandular mass.

b) The portal vein entering the under side of the liver by several branches.

c) Near it the gall duct, formed by the union of two branches and proceeding as a slender tube to open into the duodenum about an inch and a half from the pyloric orifice of the stomach.

d) The spleen, an elongated red body lying behind and to the left of the stomach.

e) The portal veins; trace them to the liver.

7) Divide the gullet at the top of the neck, and the rectum close to the anus, and severing attachments, remove the whole tube; then cut away the mesentery and spread it out at full length.

a) Note the relative length and diameter of its various parts and determine the ratio of its length to the body length.

8) Open the stomach along its greater curvature.

a) Note the thin smooth mucous membrane which lines the fundus, and is sharply marked off from the thick corrugated mucous membrane lining the rest of the organ. (This is not the case in the human stomach.)

b) Examine under water the surface of the lining membrane with a hand lens.

9) Remove the liver.

a) Note its general form.

b) Scrape its cut surface and examine cells in normal salt solution under microscope.

10) Cut out piece of the intestine (or that of calf), wash inner surface gently with normal salt solution and examine in solution with a hand lens. Or

11) Place a piece of small intestine or that of calf in 50% alcohol for twenty-four hours. Then open and examine the villi under water with a hand lens.

DIGESTION.

Materials: Blood fibrin. This can be obtained by stirring fresh blood. Dried fibrin may be used for digestion experiments, or

Egg albumin, coagulated. Stir white of egg into

boiling water acidulated with vinegar or acetic acid.

Meat juice.

Bile of pig or other animal obtained from butcher.

Glycerole pepsin. Buy of druggist or collect by taking the middle portion of fresh stomach of pig, scraping off the mucous membrane, adding glycerin, and allowing to stand several days, stirring occasionally. Use a few drops for each experiment.

Pancreatic extract. Purchase of druggist or prepare from fresh pancreas, by grinding thoroughly with sand in a mortar. *a*) Add water to one half and filter through cloth, for amylolytic ferment. *b*) Add three or four volumes of glycerin to the remainder and allow to stand several days, for proteolytic ferment.

Saliva. Collect by chewing paraffin or a piece of rubber, and filter.

0.2 per cent solution of hydrochloric acid. Add 6.5 c.c. commercial hydrochloric acid to 1 liter of distilled water.

Apparatus: Water bath for holding test tubes in digestion experiments. An oblong deep tin pan, containing a wire test tube rack, nearly filled with water and heated by a Bunsen burner, lamp or alcohol lamp will answer. Temperature should be kept at 99° F. (38° C.).

Thermometer. Those with scales on stem or in glass tubes to be preferred.

Test tube racks. Wire racks with a capacity for three dozen test tubes are useful in water bath.

Wooden test tube racks with holes and pins should be supplied to the tables.

Dialyzer (Fig. 66, p. 145). This may be made from a section of a lamp chimney, one end being covered with bladder, intestine, or moist parchment paper.

Funnels. For students' use, they should be two inches in diameter; for preparing material, six or eight inches.

Test tubes. A dozen six-inch test tubes for each student.

Beakers. Nests of three beakers of from four to six ounce capacity.

Filter papers. Three inches in diameter is a convenient size. A few of six or eight inches diameter will be needed.

Litmus rubbed up in boiling water and filtered.

Demonstrations:

1) Penetration of animal membrane (dialyzer) by crystalloids (sugar, salt) and peptone.

2) Non-penetration of animal membrane (dialyzer) by colloids (starch, albumin) except peptone.

Experiments: * Use a test tube for each experiment. Identify them by slipping bits of paper con-

* The digestion ordinarily requires a number of hours, and it may be best to prepare the solutions, put them in the water bath, and leave them until the next day for examination. The digestion of starch and of fibrin if shaken every few minutes is so rapid that it may be possible to get the proper reactions after a few minutes for starch and after half an hour for fibrin. If the laboratory section extends for two hours, as it should during the digestion work, the digestions may be sufficiently completed at the end of that time for all the characteristic tests. It is best under these circumstances to have the pupils prepare test tubes first. then have the demonstrations and experiments which can be accom-

taining names of students and contents in the open end. Place the test tubes for all digestion experiments in that portion of the water bath reserved for each student. It is best to use small amounts of substances for digestion, and fill the test tubes about two thirds full of solution. Two or three drops of the solution of pepsin and of pancreatic extract are sufficient. Shake frequently.

1. *a*) Effect of saliva on starch (38° C.).
   b) " " proteid (38° C.).
   c) " " fat (38° C.).
   d) Influence of temperature (about 18° C. and 60° C.).
2. *a*) Effect of pepsin on boiled fibrin (38° C.).
   b) " 0.2% HCl " " "
   c) " pepsin and 0.2% HCl on boiled fibrin (38° C.).
   d) Influence of temperature (about 18° C. and 60° C.) on action of pepsin and 0.2% HCl on boiled fibrin.
   e) Test product of gastric digestion (2,*c*) for peptones by means of biuret test.
3. *a*) Effect of pancreatic extract on starch.
   b) " " " fibrin or egg albumin.

plished immediately, to be followed by the examination of digestion products toward the end of the exercise. Students sufficiently interested and with plenty of time to do quantitative work, may determine the relative rapidity of digestion by artificial gastric juice and by pancreatic extract, by taking weighed amounts of fibrin, exposing them to digestion for a certain length of time, carefully washing and reweighing the fibrin to determine the amount digested. Experiments may also be made upon the time taken to digest raw and cooked starchy foods, etc., etc.

c) Influence of acidity and alkalinity on action of pancreatic extract.

d) Effect of shaking oil with pancreatic extract.

e) " " boiling fat or oil with caustic soda or caustic potash. (Test result by shaking a few drops with water.)

4. Influence of bile on absorption of fats.

   a) Moisten a filter paper stretched across top of a funnel with bile and put on paper a teaspoonful of oil. Moisten another filter paper similarly placed with water and apply the same amount of oil. Note comparative rapidity of penetration.

STRUCTURE AND COMPOSITION OF BLOOD.

Materials: Frog.
Ether.
Blood clot.
Defibrinated blood.
Blood serum.

Apparatus: Hand magnifier.
Microscope with powers up to 450.
Bundle of twigs or wire.
Two fruit jars.

Demonstrations:

1) Put a frog in a solution of one teaspoonful of ether to a quart of water, and cover the vessel for a minute or two. Remove the frog, cut off its head and collect on a piece of glass a drop of the blood which flows out. Spread out the drop so that it forms a thin layer and hold the glass up against the light.

a) Examine the blood with a hand magnifier and a microscope, noting form, size, color, and relative numbers of red and white corpuscles.

2) Wind tightly a piece of twine around the last joint of a finger; then, taking a needle, prick the skin of the side of the finger. A large drop of blood will exude. Spread it out on a piece of glass under a cover glass.
   a) Examine with hand magnifier.
   b) Examine with microscope and demonstrate
      1) Form, size, and color of human as compared with frog red blood corpuscles.
      2) Form of aggregation of human blood corpuscles.
      3) Color, form, size, and relative number of white blood corpuscles.

3) Obtain a large drop of human blood as above (2) described. Note
   a) Physical characteristics (color, opacity, etc.) when it flows from wound.
   b) Apparent change of color when it is spread very thin on the glass and held over a sheet of white paper.
   c) Color, when mixed with a teaspoonful or more of water in a wine glass.

4) Place another large drop of human blood, obtained as above, on a clean glass plate. To prevent drying up cover by inverting over the drop a wine glass whose interior has been moistened with water.
   a) In four or five minutes remove the wine glass and note the condition of the blood.
   b) Replace the moist wine glass and in half an hour examine again.

5) Collect blood at butcher's in a glass jar; set aside until the blood clots and carry it home with the least possible shaking. Observe the clot and serum next day; carefully collect latter.

6) Collect blood in the pail and beat it vigorously with the twigs for three or four minutes.
   a) Note quantity of stringy elastic material (fibrin) collected on the twigs.
   b) Wash the twigs thoroughly with water and observe color of fibrin.

7) Take some of the serum from specimen 5.
   a) Note physical characteristics.
   b) Heat it in a test tube.
   c) Add nitric acid to some in test tube.

8) Place a small quantity of whipped blood (6) on a piece of platinum foil. Heat.
   a) Note that after the drop dries it blackens, showing that it contains much organic matter.
   b) Continue heating until this is burned away; examine the residue of white ash, consisting of the mineral constituents of the blood.

ANATOMY OF THE HEART.

Materials: Sheep's heart, not cut out of the pericardium, severed from the lungs, nor *punctured.*

Dissection * *or Demonstration :*

1) Place the heart and lungs on their dorsal side upon a table in their normal relative positions, with the wind-pipe turned away.

* The dissection may be made before the meeting of the class and the anatomical facts through 3) *c* demonstrated upon the preparation.

a) Note the pericardium and the piece of diaphragm which is usually found attached to its posterior end.

b) Inflate lungs and note relations of heart.

2) Carefully dissect away adherent fat, etc., without cutting the veins, which, being thin, collapse when empty and may be easily overlooked until injured. As each vein is found, stuff it with raw cotton.

a) Note the vena cava inferior on the under (abdominal) side of the diaphragm; thence follow it until it enters the pericardium.

b) Observe the hepatic and other veins which the vena cava inferior receives from the liver, spleen, kidneys, and diaphragm.

c) Observe the right phrenic nerve lying on the left side of the inferior vena cava and ending below in several branches to the diaphragm.

d) Find the lower end of the superior vena cava, which enters the pericardium about one inch above the entry of the inferior cava; thence trace it up to the point where it has been cut across.

e) Notice between the ends of the two venæ cavæ the right pulmonary veins proceeding from the lung and entering the pericardium.

3) Turn the right lung and the heart back to their natural position; clear away the loose fat in front of the pericardium: seek and clean the following vessels in the mass of tissue lying anterior to the heart and on the ventral side of the windpipe. Note

a) The aorta: its arch and branches.

b) The pulmonary artery imbedded in fat on the

dorsal side of the aorta; note course and follow branches into lungs.

NOTE.—Observe the thickness and firmness of the arterial walls as compared with those of the veins.

c) The left pulmonary veins on the ventral side of the left pulmonary artery, passing from the lung into the pericardium.

4) Slit open the pericardial sac, and note

a) Its smooth, moist, glistening inner surface, and the similar character of the outer surface of the heart.

b) The character and amount of pericardial fluid.

5) Cut away the pericardium carefully from the various vessels at the base, and note

a) While this is being done, that inside the pericardium the pulmonary artery lies on the ventral side of the aorta.

b) The general form and position of the heart.

6) Carefully dissect out the entrance of the pulmonary veins into the heart. It will probably seem as if the right pulmonary veins and the inferior cava opened into the same auricle, but it will be found subsequently (13) that such is not really the case. Note on the exterior the following points:

a) The flabby auricle (left) into which the veins open and its companion (right) between the aorta and the superior vena cava.

b) A band of fat running around the top of the ventricles; an offshoot from it runs obliquely down the front of the heart, passes to the right of its apex and indicates externally the position of the internal partition or septum, which sepa-

rates the right ventricle (which does not reach the apex of the heart) from the left.

7) Dissect away carefully the collections of fat around origins of the great arterial trunks and around the base of the ventricles. In the fat will be found

a) A coronary artery rising from the aorta close to the heart, opposite the right border of the pulmonary artery; it gives off a branch which runs in the groove between the right auricle and ventricle, then runs down the dorsal side of the heart.

b) The other coronary artery, considerably larger, rising from the aorta dorsal to the pulmonary artery; its main branch runs along the ventral edge of the ventricular septum.

c) The coronary veins accompanying the arteries.

8) Open the right ventricle by passing the blade of a scalpel through its wall about one inch from the upper border of the ventricle and on the right of a band of fat which marks the external partition between the ventricle (see 6, *b*); cut down towards the apex. Make a corresponding cut through the wall of the same ventricle on its other side. Raise point of wedge-shaped flap and expose cavity. Cut off the pulmonary artery about an inch above its origin and open the right auricle by cutting a piece out of its wall at the left of the venæ cavæ.

a) Pass the handle of a scalpel from the ventricle into the auricle, and also from the ventricle into the pulmonary artery; study out the relations of these openings.

b) Slit open the auricle; note the fleshy projections

(columnæ carneæ) on its walls, and the smoothness of the interior surface of the auricle. Observe the apertures of the venæ cavæ, and note that the pulmonary veins do not open into this auricle.

c) Behind or below the entrance of the inferior cava, note the entrance of the coronary sinus.

d) Pass a probe through the aperture along the sinus and slit it open; notice the muscular layer covering it in.

9) Raise by its apex the flap cut out of the ventricular wall, and if necessary prolong the cuts toward the base of the ventricle until the divisions of the tricuspid valve come into view, and note

a) The columnæ carneæ on the wall of the ventricle, and the muscular cord (not found in the human heart) stretching across its cavity.

b) The prolongation of the ventricular cavity towards the aperture of the pulmonary artery.

10) Cut away the right auricle.

a) Examine carefully the triscupid valve, composed of three membranous flexible flaps, thinning away towards their free edges; proceeding from near these edges are strong tendinous cords (chordæ tendineæ), which are attached at their other ends to muscular elevations (papillary muscles) of the wall of the ventricle.

11) Slit up the right ventricle until the origin of the pulmonary artery comes into view. Looking carefully for the flaps of the semilunar valves, prolong the cut between two of them so as to open the bit of pulmon-

ary artery still attached to the heart. Spread out the artery.

a) Examine the valves.

b) Observe the pouch made by each flap and the slightly dilated wall of the artery behind it.

c) Note that the free edge of the valve is turned from the heart, and has in its middle a little nodule (corpus Arantii).

12) Open the left ventricle in a manner similar to that employed for the right. Then open the left auricle by cutting a bit out of its wall. Cut the aorta off about half an inch above its origin from the heart, and note

a) The aperture between left auricle and left ventricle.

b) The passage from the ventricle into the aorta.

c) The entry of the pulmonary veins into the auricle.

d) The septum between the auricles and that between the ventricles.

13) Pass the handle of a scalpel from the ventricle into the auricle; another from the ventricle into the aorta; also pass probes into the points of entrance of the pulmonary veins.

14) Slit open the left auricle and note

a) The columnæ carneæ, and the smoothness of the inner wall.

b) The columnæ carneæ of the ventricle, also the considerable thickness of the wall as compared with that of the right ventricle or of either of the auricles.

15) Carefully raise the wedge-shaped flap of the left ventricle, and cut toward the base of the heart, until

the valve (mitral) between auricle and ventricle is brought into view.

a) Note that one of its two flaps lies between the auriculo-ventricular opening and the origin of the aorta.

b) Examine in these flaps their texture, the chordæ tendineæ, the columnæ carneæ, etc.

c) Examine the semilunar valves at the exit of the aorta.

16) Slit the aorta carefully between two of these valves.

a) Examine the bit of aorta still left attached to the heart and note the thickness of its wall, its extensibility in all directions, its elasticity and firmness.

b) Note the valves.

c) Note the origins of the coronary arteries in two of the three dilatations of the aortic wall above the semilunar flaps.

d) Compare the artery with the veins which open into the heart.

HEART ACTION.

Materials : Frogs.*
Ether.
Two sheep's hearts.

Apparatus : A piece of sheet cork or of thin board with a half-inch hole cut in it.
Microscope.
Caliper rule.

* Anatomically a frog's heart differs in many respects from that of a mammal, but the phenomena of systole and diastole are essentially the same.

Recording apparatus, similar to that used for muscle.

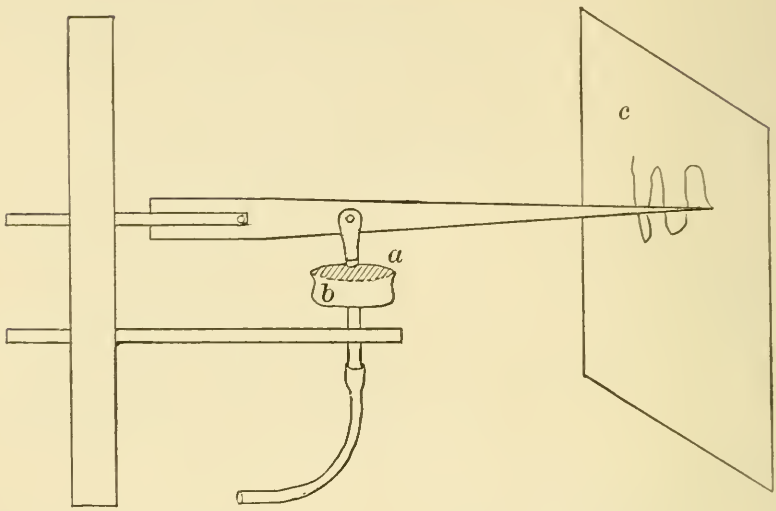

FIG. 150.—Diagram of Marey tambour apparatus for recording curves. *a*, the rubber membrane coinciding with the movements of the membrane of the transmitting apparatus; *b*, tambour; *c*, smoked glass plate.

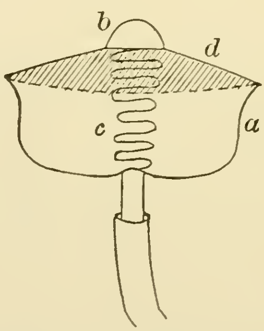

FIG. 151.—Diagram of cardiograph. *a*, cup; *b*, knob; *c*, spring; *d*, rubber membrane.

Cardiograph.

Marey tambour.

Circulation apparatus made from bulb syringe, such as may be obtained at the drug store.

Manometer.

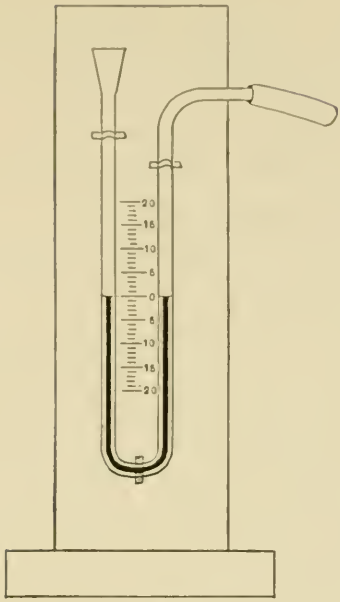

FIG. 152.—Manometer.

Several feet of glass tubing.

Glass nozzle (glass tubing drawn out in flame).

Scalpel.

A piece of sheet lead such as comes in tea chests.

Scissors.

Forceps.

Rod, ½ inch diameter (a small test tube).

Glass window (a circular piece of glass 1½ inches in diameter, cemented into a short tin tube).

Graduate.

Two basins.

Demonstrations :

1) Take a medium-sized frog. Wrap it carefully in a damp cloth and then in tea lead so that one foot is outside the lead. Fasten it to perforated sheet cork or board

and pin or tie toes so that the web of foot is spread over hole. Clamp in place on microscope stage. Focus carefully on web. Note

a) Movement of blood corpuscles.

b) Blood vessels in which blood is passing toward finer branches (arteries).

c) Smallest vessels through which blood is passing (capillaries).

d) Vessels in which blood is passing from small branches to large trunks (veins).

e) Rapidity of movement of red blood corpuscles and position in blood stream Also bending of red blood corpuscles at arterial branches.

f) Movement of white blood corpuscles and their position in blood stream.

g) Intermission of blood flow (?) and coincidence with heart beat.

2) Cut the medulla oblongata of an etherized frog by nicking with the point of scalpel at right angles to the length of the body in the line joining posterior margins of the ear disks. Introduce a blunt wire and destroy the brain * and spinal cord. Run a pointed match into the cut to prevent bleeding.

Lay the animal on its back, and carefully divide with scissors the skin along the middle line of the ventral surface for its whole length. Make cross cuts at each end of this longitudinal cut and pin out the flaps of skin.

Next pick up with forceps the remaining tissues of the ventral wall near its posterior end, and divide them longitudinally a little on the left side of the

* The frog is in this way painlessly killed.

middle line, being very careful not to injure either the viscera in the cavity beneath or a large vein (anterior abdominal) running along the wall in the middle line.

About the point where the vein passes from the wall to enter among the viscera of the ventral cavity are the bony and cartilaginous tissues of the sternal region. Raise the posterior cartilage with the forceps, make a short transverse cut in front of the vein, and, looking beneath the sternum, note the pericardium with the heart beating inside. Divide the fibrous bands which pass from the pericardium to the sternum and with scissors cut away sternum, etc., taking great care not to injure the heart.

Push a rod of about half an inch in diameter down the throat so as to stretch the parts; then picking up the pericardium with the forceps, open it and gently cut it away.

a) Note the parts of heart:

1) Ventricle, single in case of frog.
2) Auricles, right and left.
3) Bulbus arteriosus on front aspect of heart.
4) Sinus venosus under the heart, seen by gently raising the apex.
5) Two aortas.
6) Pulmonary veins and venæ cavæ.

b) Note systole and diastole of heart.

c) Changes of color and size of its parts.

d) Determine the order of contraction of the different parts.

e) Put aside under a bell-jar with a wet sponge, or a

piece of flannel soaked in water. Note duration of heart beat.

3) To demonstrate the action of the valves of the heart, carefully remove a sheep's heart from the pericardium.

a) Aortic valve.

1) Cut off aorta one inch above valves. Tie into it a piece of glass tubing, down which pour water. Note the efficiency of the valves.

2) Tie a piece of glass tubing into one pulmonary vein and tie off the other. Fill the tubing with water. Squeeze ventricles with hand and note results.

b) Mitral valve.

1) Tie into the left auricle a glass window and watch appearance of mitral valve as ventricle is squeezed and relaxed.

c) Mitral and tricuspid valves.

1) Carefully cut the auricles away from another sheep's heart, taking great care not to injure the ventricles or the auriculo-ventricular valves. Then holding the ventricles, apex down, in one hand, pour water in a stream into them from a pitcher held about a foot above. Note the movement of the mitral and tricuspid valves.

4) Take bulb syringe and fit the outflow tube to receive either a piece of glass tubing about two feet long or a piece of pure gum rubber tubing (one inch "sap" tubing); also prepare nozzle with a hole about $\frac{1}{64}$ inch in diameter which can be fitted to the distal end of

either glass or rubber tube. A basin of water and another basin into which to receive the discharge are needed.

a) Put aspirating end of bulb syringe in a basin of water; fill syringe; attach glass tube; squeeze and release bulb regularly every two seconds. Note character of outflow and measure amount for 10 or 20 seconds.*

b) Attach nozzle to end of glass tube; pump regularly as before and note character of outflow; measure outflow.

c) Remove glass tube and attach rubber tube. Pump as before, noticing character of outflow, and measure the outflow for same period.

d) Attach nozzle to rubber tube and test as in *b*).

e) Determine factors contributing to uniform flow.

f) Connect a manometer with the arterial side of the apparatus and measure pressures developed in *a*, *b*, *c*, and *d*.

g) Determine the relation of the internal pressure to the size of the rubber tube in *d* (the flow may be conveniently stopped for these measurements).

h) Attach a large tube to nozzle (to represent vein) in *d* and connect another manometer to it. Compare pressures.

5) Record human pulse curve by pressing knob of cardiograph (Fig. 151) on carotid artery at side of larynx by means of a band around neck. Connect this with a Marey tambour (Fig. 150) on recording appa-

* Attempt should be made to squeeze the bulb with the same force throughout these experiments.

ratus and move the smoked glass * over the writing point to separate the records.

a) Note the general form of curve.

b) Note the dicrotic wave.

c) Interpret curve in relation to size of artery.

ANATOMY OF THE RESPIRATORY TRACT.

Materials: Sheep's lungs with windpipe and heart attached, to prevent puncturing of lungs through careless removal of heart.

Rat or kitten.

Frog.

Chloroform.

Normal salt solution.

Apparatus: A few inches of glass and of rubber tubing about $\frac{1}{2}$ inch diameter.

Some small object, as a piece of cork or rubber.

Microscope.

Dissection or Demonstration:

1) Examine the windpipe of the sheep and trace its division into the bronchi.

a) Notice in its wall the horseshoe-shaped cartilages, which keep it open and which are so arranged that the dorsal aspect of the tube (which lies against the gullet) has no hard parts in it.

2) Slip a rubber tube on the end of the glass tube and insert the other end of the glass tube into the trachea; tie firmly; blow out lungs and tie rubber tube to keep distended. Note

a) The extensibility and elasticity of the lungs.

* The record may be "fixed" by flowing the plate with dilute shellac varnish and letting it dry.

b) The size and form the lungs assume when distended.

c) The space for the heart.

d) The concavity of the lower (diaphragm) surface of the distended lungs.

e) The lobes.

f) The pleural membrane.

3) Trace one bronchus to its lung.

a) Cut through the lung tissue and follow the branching bronchi through the lung.

b) Note the cartilage rings in their walls.

c) Note mucous membrane lining tubes.

d) Wash surface with normal salt solution; gently scrape with scalpel and examine scrapings, under microscope.

4) Remove from a chloroformed rat or kitten the abdominal viscera, cutting away the liver and stomach with especial care.

a) Examine the vaulted diaphragm and through it the lungs.

5) Seize some of the folds of the peritoneum attached to the diaphragm and pull it down, imitating its contraction and flattening in inspiration.

a) Observe corresponding movements of lungs.

6) Make a free opening into one side of the thorax.

a) Note behavior of lung.

7) Open the other side of the chest.

a) Note result upon the lung.

b) Observe the structure of the diaphragm (its tendinous centre and muscular periphery) and also the attachment of the pericardium to its thoracic side.

8) Place a recently killed frog on its back. Fasten lower jaw wide open.
   a) Place small object on roof of mouth near nose. Note movement.
   b) Examine scraping from roof of mouth in normal salt solution under microscope.

9) Remove as much of œsophagus as possible; split it open and pin out.
   a) Place small object upon it near mouth end; note behavior.
   b) Set aside under moist glass; note position of mucus on surface at end of a half-hour.*

RESPIRATION.

Materials: Wood shaving.
Lime water.
Hydrochloric acid.
Blood clot, defibrinated blood or piece of liver.
Lungs of cat or rat.

Apparatus: Thermometer.
Mirror.
Wide-mouthed bottle.
Test tube.
Glass tubes.
Rubber tubing.
Bell-jar of two quarts' capacity.
Sheet rubber.
Pinchcock.

* Cilia are present in the respiratory passages, but not in the œsophagus of man.

Rubber stopper with double perforations, to fit bell-jar.

Two pieces of glass tubing, one bent, to fit perforations of stopper.

Water-valve respiration apparatus for carbon dioxide.

Experiments and Demonstrations:

1) Note the effect of breathing

a) On the bulb of a thermometer.

b) On a mirror, knife blade or other polished metallic surface.

2) Burn a shaving in a wide-mouthed bottle of air and close tightly.

a) Pour lime water into the bottle and shake. Note result (carbonate of lime).

b) Pour a few drops of hydrochloric acid into *a*) and note result.

c) Blow breath through a tube into a solution of lime water.

d) Add hydrochloric acid as in *b*).

e) Demonstrate by means of the water-valve respiration apparatus (Fig. 153) the relative amounts of carbon dioxide in atmospheric air and in expired air, by partly filling bottles with lime water and breathing through them.

3) Blow breath through a weak solution of lime water colored with phenolphthalein.*

4) Cut open blood clot or piece of liver.

a) Compare freshly cut surface with surface exposed to air.

* Phenolphthalein is pink in alkaline solutions, colorless in acid.

b) Place freshly cut piece of blood clot or liver into a bottle containing oxygen. Or

b') Shake defibrinated blood in bottle containing oxygen. Note result (oxyhæmoglobin).

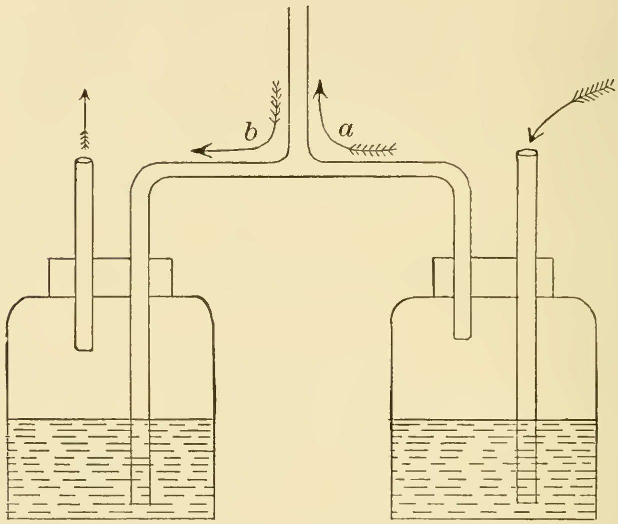

FIG. 153.—Apparatus to demonstrate carbon dioxide in expired air. *a*, inspiration; *b*, expiration.

5 Connect manometer by a piece of rubber tubing with a piece of glass tubing in the mouth; place also in the mouth a short piece of tubing $\frac{1}{4}$ to $\frac{1}{2}$ inch diameter.

a) Breathe as ordinarily; note changes in pressure as shown by manometer.

b) Breathe quickly; note changes as above.

6) Substitute for glass tubing in 5) a glass tube drawn out to a point.

a) Breathe as ordinarily; note pressures.

b) Breathe strongly; note pressures.

7) Connect the distant end of the rubber tubing from the tube in the mouth to the Marey tambour and record the curves made by the writing point.

8) Illustrate the action of the diaphragm by substituting for the chest wall a bell-jar of two quarts' capacity (Fig. 154). Tie the lungs of a cat or a rat on a long piece of glass tubing which is then passed up from

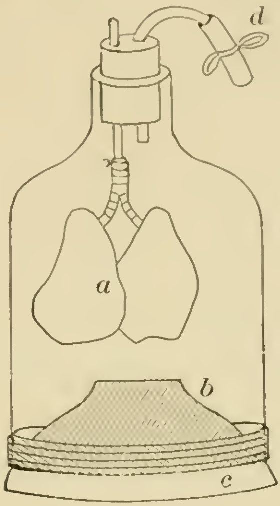

FIG. 154.—Breathing apparatus. *a*, lungs of cat; *b*, rubber diaphragm; *c*, bowl; *d*, pinchcock.

beneath through one of the perforations in the stopper. Seat the stopper firmly in the mouth of bell-jar. Stretch a piece of heavy pure gum sheet rubber over the larger end of the bell-jar and tie it firmly in position. Press the rubber membrane down on the top of a bowl and close the rubber tube at the end of the bent glass tube with a pinchcock.

a) To represent inspiration, lift the bell-jar from the bowl, allowing the rubber membrane to flatten.

b) To represent expiration press the membrane on the bowl.

c) To represent the effect of a puncture of the chest wall, open the bent tube, when the jar is lifted from the bowl.

RENAL ORGANS.

Materials :

Rat.

Chloroform.

Fresh sheep's kidney.

Apparatus :

Sponge.

Bell jar.

Stout scissors.

Bristles.

Dissection or Demonstrations :

Kill a rat by placing it under a bell-jar with a sponge soaked in chloroform.

1) Open the abdomen, remove the alimentary canal, and cut away with stout scissors the ventral portion of the pelvic girdle. Note the dark red kidneys on each side of the dorsal part of the abdominal cavity, the right one nearer the head than the left.

2) Dissect away the connective tissue, etc., in front of the vertebral column, so as to clean the inferior vena cava and the abdominal aorta.

   a) Trace out the renal arteries and veins.

   b) Find the ureter, a slender tube passing posteriorly from the kidney, and trace it to the bladder.

3) Dissect away the tissues around the urinary bladder. Note its form, etc.

4) Open the bladder.

   a) Find the orifices of the ureters, and pass bristles through them.

b) Note the mucous membrane lining the bladder.

5) Remove one kidney from the body and divide it from its outer nearly to its inner border; turn the two halves apart. Examine the cut surfaces and note

a) At the inner border the dilatation of the ureter.

b) The outer cortical portion of the kidney.

c) The medullary portion.

d) The papillæ.

6) Obtain a fresh sheep's kidney. Divide it from its outer to its inner border, and demonstrate

a) On the cut surfaces the cortex and medulla.

b) The pyramids of Malpighi and the offshoots of the cortex extending between them.

ANATOMY OF THE NERVOUS SYSTEM.

Materials:

Frog.

Ether.

Fresh calf's or sheep's head.

Alcohol.

Apparatus:

Stout scissors.

Bone forceps.

Dissection or Demonstrations:

Kill a frog with ether; open its abdomen and remove the viscera.

a) Note at the back of the abdominal cavity a bundle

of white cords (nerve trunks) passing to each leg.

b) Trace the sciatic nerve into which they unite and dissect it along its course until it ends in fine branches in the hind leg.

2) With stout scissors cut very carefully bit by bit the bodies of the vertebræ (which will be seen projecting in the middle line at the back of the abdominal cavity) until the neural canal is laid open and the spinal cord exposed. Note

a) The origin of the nerves from the spinal cord.

b) Their division into anterior and posterior (ventral and dorsal) roots before they join the cord.

c) The ganglionic enlargements on the posterior roots.

3) Turn the frog upon its abdomen and remove the skin and muscles on the dorsal side of the spinal column. With great care cut away the upper two thirds of the neural arches of the vertebræ. Then remove the upper half of the skull cavity. Gently raise the brain and spinal cord, divide the nerves which spring from them and lift out the whole cerebro-spinal system and place it in alcohol for twenty-four hours.* Note

a) The origin of nerves from both brain and cord.†

b) The union of the brain and cord, etc.

4) Dissect away the skin and muscles covering the

* The specimen may be hardened and preserved in a solution—formalin, 2 parts; alcohol, 20 parts; water, 78 parts.

† A frog's brain differs in many important points from that of a mammal, as in the very small cerebellum, the comparatively small cerebral hemispheres, the comparatively large mid-brain and the absence of convolutions.

cranium of a calf's or sheep's head. Then with a small saw very carefully divide the bones in a circular direction, so as to cut off the crown of the head. Next carefully remove the loosened bones of the top of the skull, tearing them away from the dura mater lining them.

a) Demonstrate the tough dura mater enveloping the brain.

b) Cut it away and note the processes which it sends between the two cerebral hemispheres and between the cerebellum and the cerebral hemispheres.

c) Cut the membrane away and note

  1) Its glistening inner surface, due to the arachnoid membrane lining it.

  2) The pia mater full of blood vessels and closely attached to the brain.

  3) The glistening arachnoid layer covering the exterior of the pia mater.

d) Put the specimen aside in the hardening solution for a day or two. When the brain has become somewhat hardened dissect away the pia mater on one side and show

  1) The cerebral hemispheres and their surface convolutions.

  2) The cerebellum and its foldings.

  3) The medulla oblongata beneath the cerebellum.

e) With bone forceps cut away the remainder of the sides and roof of the skull. Find

  1) Nerves to eyes.

  2) Nerves to nose.

f) Raise the brain in front and cut through the vessels, nerves, etc., which attach it to the base of the skull cavity; remove it from the skull cavity.

1) The cerebral hemispheres, which overlap the cerebellum much less than in man.
2) Cerebellum.
3) Mid-brain, etc.
4) Stumps of the cranial nerves attached to the base of the brain.*
5) Optic commissure, with the optic tracts leading to it.
6) Stumps of the optic nerves leading from it.

g) Make sections across the brain in different directions and note

1) Gray matter spread over most of its surface.
2) The nodules of gray matter imbedded in its interior.

NERVE ACTION.

Materials: Frog.
Blotting paper.
Vinegar.

Apparatus: Stout scissors.
Feather.
Bone forceps.
Blunt wire.

Demonstrations or Experiments:

1) Feign a blow at a person's eye after having told him that he is not to be actually struck.

* Most of these will have been torn off unless the dissector has some technical skill.

2) *a*) Count a boy's pulse and breathing while he is sitting quietly.

b) Let him run a hundred yards at full speed, and immediately count pulse and breathing movements. Compare results.

3) Tickle the inside of the nose with a feather.

4) Place a live frog on a table and note its movements and reactions to varying conditions:

a) Breathing.

b) Winking.

c) Jumping, etc.

Voluntary Reaction (Chain Reaction):

5) Divide the class into two equal groups so arranged in series that a signal may be passed from one to another of each group by touching hands. Let some one give a signal by touching the hand of each of the first members of the two series. As soon as the pressure is felt, let them transmit it to the next and so on until finally the last members of the series press on the hands of the instructor, who decides which signal came first.*

a) Chain reaction with eyes shut.

b) Chain reaction by one series with eyes shut, other series looking on.

c) Conditions in *b*) reversed.

Reflex Reaction:

6) Prepare a frog † by destroying its brain as soon as it is under the influence of ether.

* To record roughly the time of a single reaction or of a chain reaction, the inventive teacher can use a pendulum beating seconds and a recording apparatus such as was used for cardiograph tracings, with a Marey tambour to transmit the signal.

† This is best done an hour or two before the experiment.

a) Note reactions of frog

1) When toe is pinched.

2) When small bits of blotting paper soaked in vinegar are put one by one on different regions of its skin. (Dip the animal in clean water after each application to wash away the vinegar.)

b) Destroy its spinal cord by running a blunt wire down the neural canal. Repeat *a*) and compare results.

c) Turn frog (*b*) on its back and carefully expose the origins of the sciatic nerves. Pinch these and note result.

SPECIAL SENSES.

DERMAL SENSES.

Apparatus: Drawing compasses (any form, not too sharp, may be used).

Scale graduated to millimeters.

Vessel of cold water.

Vessel of lukewarm water.

Vessel of hot water.

Forceps.

Experiments (two students working together):

1) Take a straight piece of hair in forceps and, by ascertaining the greatest length which will give rise to a sensation of pressure, determine the relative sensitiveness of

a) Palm.

b) Back of hand.

c) Forehead.

2) What is the least distance that the two points of the compasses may be separated and still be recognized as two when applied to
   a) Finger tip?
   b) Back of hand?
   c) Back of neck?
3) *a*) What sensations are caused by the light pressure of a pencil point on the back of the hand?
   b) Are the cold points constant in their position? (Test from day to day.)
4) Temperature sense.
   a) Put a finger of the right hand into warm water and a finger of the left hand into cold water. Note the immediate sensations and the change in sensations after the fingers have remained some time in the water.
   b) Withdraw the fingers and plunge both immediately into the vessel containing lukewarm water. Compare the sensations of the two fingers.

TASTE AND SMELL.*

Materials: Onion.
Sugar.
Salt.
Dilute Vinegar.
Carrot.
Dilute ammonia (one drop of strong ammonia in a glass of water).
Cabbage.
Quinine.

Experiments (two students working together):

1) Eliminate odor by holding the nose and determine

* Care should be taken not to exhaust the sense organs by over-stimulation.

a) Which of these materials have odor.
b) Which have taste. Classify them.
c) Where "taste" is located in the mouth.

HEARING.

Apparatus : Tuning fork and resonance chamber.
Stretched wire or catgut (violin).
Violin bow.

Demonstrations and experiments :

1. Sound dependent on vibration.
2. Pitch* " " rapidity of vibration.
3. Volume " " extent of vibration.
4. " " " resonance.
5. Test of acuteness of hearing with watch at varying distances from ear.
6. Test the sense of direction by hearing,
   a) Using both ears and closing eyes.
   b) Using one ear " " ".

VISION.

Materials : Fresh eye of white rabbit, calf or sheep.

Apparatus : Cards with two parallel fine black lines ½ m.m. apart.
Cards for blind spot (spots 2 in. apart).
Worsteds for color test (Milton Bradley). One skein of each of the standard prismatic colors with their tints and shades will supply a large class if cut up into small hanks.

* Pitch may be graphically demonstrated by means of a manometric flame and a revolving mirror, using the voice or a cornet for the production of tones.

Color top with color disks (Milton Bradley).

Prism. A small glass prism, 60° angles.

Photographic camera. Any photographic camera which has a ground glass will answer.

Spectacle lenses, concave and convex.

Candle.

Screen, a piece of cardboard placed in a vertical position on base.

Demonstrations :

1) Remove eye from the socket of a freshly killed rabbit. Point eye toward a window and note
   a) Image of window on retina.
   b) Size and inversion of image.

2) Demonstrate formation of image by a lens. Use a camera with ground glass, or an ordinary magnifying glass, and receive image on paper.

3 Demonstrate effect of diaphragms on brightness and sharpness of image.

4) Analyze white light by means of a prism, throwing spectrum on white paper.

5) Mix colors by means of color top.
   a) Black with white in different proportions (grays).
   b) Various colors with white (tints).
   c) " " " black (shades).
   d) " " " each other.

6) Test color blindness by giving to pupil a set of the standard colors and their tints and shades ; hold up color and ask for the selection of all pieces resembling it.

7) Use lenses and lighted candle for the formation of actual images.

a) Near sightedness. Arrange screen just behind the focus of lens (image on screen somewhat blurred). Place concave spectacle lens in front of magnifying glass and note result.

b) Far sightedness. Arrange screen just in front of the focus of lens (image on screen somewhat blurred). Place convex spectacle lens in front of magnifying glass and note result.

8) Indicate by means of diagrams

a) Corresponding parts of retinæ.

b) How size and distance of objects are estimated.

Experiments :

1) Sharpness of vision.

What is the farthest distance at which the two parallel lines on card can be seen as two (using one eye)

a) When card is held in line of vision ?

b) When card is held 20° away from line of vision ?

2) Changes in iris.

a) Sit facing a window ; cover one eye with hand for one minute. Quickly uncover eye and note changes in pupil by means of a mirror.

b) Observe eye of companion in a uniformly lighted room or out of doors, and compare the size of pupil when looking at a distant object with that when looking at an object six inches away.

3) Blind spot.

What is the distance at which the right hand spot on card disappears when one looks at the left spot with right eye, holding the card so that the spots are on the same level ?

(Draw a diagram of an eye and locate the axis of vision, blind spot, lens, iris, cornea, retina.)

4) Accommodation: Determine the range of accommodation in your own eye.

5) Binocular vision.

   a) Hold two pencils vertically in front of the eyes, one at a distance of one foot, the other at two feet. When looking at either one what is the appearance of the other, and why? Show by diagram.

   b) Under what conditions do you see "single" when using both eyes?

6) What are the movements of the eyeballs in changing from far to near vision?

7) Test visual judgment of

   a) The sizes of disks of different colors (black, white, red, etc.) but of the same size.

   b) The lengths of vertical and horizontal lines of the same length.

   c) The two halves of a line, one of which is crossed by several short lines.

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HUMAN BODY

MARTIN

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